AN ELEMENTARY

TEXT-BOOK OF ZOOLOGY

FOR INDIAN STUDENTS

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AN ELEMENTARY TEXT-BOOK OF ZOOLOGY FOR INDIAN STUDENTS

ADAPTED FROM

"AN ELEMENTARY COURSE OF PRACTICAL ZOOLOGY"

BY

PROFESSORS T. J. PARKER AND W. N. PARKER

BY

B. L. BHATIA, M.Sc., F.Z.S., F.R.M.S.,

KAISAR-I-HIND MEDALLIST, PRINCIPAL, GOVERNMENT COLLEGE, HOSHIARPUR, MEMBER SCIENCE FACULTY AND BOARD OF STUDIES, PUNJAB UNIVERSITY, FORMERLY ASSISTANT PROFESSOR OF ZOOLOGY, GOVERNMENT COLLEGE, LAHORE

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PREFACE

During recent years a considerable advance has taken place in the teaching of Zoology in Indian Colleges, and the want of a suitable text-book describing the Indian types has been keenly felt for some time. English text-books have had to be used so far, and the students had to be constantly warned as to the differences that might exist between the anatomy of the type actually used for study and the corresponding one described in such text-books. After a fairly long experience gained in teaching the subject, I made up my mind to do something to remove this long-felt want, so far as the Intermediate students in Indian colleges were concerned. Yet I felt that no useful purpose would be served in entirely re-writing the descriptions of several familiar animals, where the existing accounts could with comparatively slight modifications serve the purpose equally well. It was consequently decided to adapt the well-known "Elementary Course of Practical Zoology" by T. J. Parker and W. N. Parker for the purpose I had in view, and my obligations are due to the publishers and to Professor W. N. Parker for their ready acquiescence in my proposal.

I found myself in close agreement with the views of the original authors as regards the general plan of the

book, and the following chief points on which they had originally agreed among themselves :—

"1. To adopt the method pursued in Huxley and Martin's 'Elementary Biology' of giving a connected account of each example. 2. To give brief practical directions which should serve mainly as a guide, the student being able to refer, in case of difficulty, to the descriptive account preceding them. 3. In the larger animals, to arrange for as much work as possible to be done on one specimen : there is much to be said in favour of this plan apart from the fact that the average student cannot give sufficient time to the subject to dissect a fresh specimen for each system of organs. 4. To begin the course of instruction by an introductory study of one of the higher animals ; to include in this introduction the elements of Histology and Physiology ; and to select the Frog for the purpose : after trying various methods, I have found this plan to be the most satisfactory in practice. 5. To give drawings and diagrams of difficult dissections, and of details which the beginner cannot as a rule make out satisfactorily for himself. . . . 6. To include a short account of methods and technique limited to the barest essential outlines. . . ."

The following paragraphs might also be quoted from the preface to the original book, as indicating its general plan. "The time such students can devote to an elementary course in the subject is limited ; and throughout the book I have borne in mind that the main object of teaching Zoology 'as a part of a liberal education is to familiarise the student not so much with the facts as with the ideas of the science,' but at the same time that he should be provided with a sound basis of facts so arranged, selected, and compared as to carry out this principle."

"Our original intention was to include one or more

example of each of the larger phyla, and also to add a practical exercise after each type, giving general directions for the examination of an allied form for comparison. But I found that this would be impossible within the space of a single volume, and it was therefore necessary to limit the descriptions mainly to those animals to which the students for whom the book is chiefly intended have to give special attention. This has resulted in rather a heavy balance on the side of Vertebrates ; but, on the whole, I think that if sufficient work is done on the lower animals to illustrate certain main facts and generalisations, a comparative study of several vertebrates forms as good a training as any for beginners—more especially in the case of medical students."

The original being avowedly an elementary course of "Practical Zoology" is naturally based on the "type-system," the advantages and dangers of which are now well-known and fully recognised. In converting the book therefore into a more general text-book, an effort has been made to include after the description of each type a brief summary of the characters of the class to which the type belongs, and a number of other animals are also mentioned which the students would do well to examine. In Part I and Chapters I, II, IV, V, and IX of Part II such modifications have been made as were necessitated by the substitution of Indian types for those dealt with before. Chapters III, VI, VII, X of Part II are written specially for this book. Chapter XI, dealing with Mammalia, has been revised and enlarged by the addition of a general elementary survey of the class. And finally two chapters dealing with the important subjects of Evolution, Variation, and Heredity have been added at the end. In these chapters an attempt has been made to introduce the student to some of the more important generalisations and con-

clusions so far arrived at in the domain of biological thought, only to an extent that would be justified on the basis of facts which he may be supposed to have gathered together. In its present form the book will be found to cover fully the syllabuses for the Intermediate Examination in Science as laid down by the various Indian Universities.

In order to make the book more useful, about one hundred extra diagrams have been added, of which a certain number are new, and specially drawn for this book from actual specimens or dissections made by the author. Others have been modified or copied from the works of well-known authors, to whom due acknowledgment is made in every case.

I am deeply indebted to Professor J. Stephenson, D Sc., C.I.E., University Professor of Zoology in the Punjab University, under whom the author has had the privilege of working for the last thirteen years, and to whose great learning and unrivalled experience as a teacher in this country the author himself owes so much, for his kindness in reading through a considerable part of the manuscript and suggesting many useful additions and alterations.

B. L. BHATIA.

GOVERNMENT COLLEGE, LAHORE,
November, 1919

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AN ELEMENTARY TEXT-BOOK OF ZOOLOGY

PART I

CHAPTER I

SCOPE OF THE SCIENCE OF BIOLOGY—THE FROG PRELIMINARY SKETCH OF ITS STRUCTURE, LIFE-HISTORY, AND VITAL FUNCTIONS—HINTS ON DISSECTION AND DRAWING

Biology, Zoology, and Botany:—There is a good deal of misconception as to the scope of the science of Biology. One often meets with students who think that while the study of animals as a whole is Zoology and the study of plants as a whole Botany, Biology is the study of a limited number of animals and plants, treated as if they had no connection with anything else,—even with one another.

This is quite wrong. Biology is the master-science which deals with all living things, whether animals or plants, under whatever aspect they may be studied. Physiology, treated for practical purposes as a separate subject, is a branch of biology; so is anatomy, to which the medical student devotes so much time; so are botany

and zoology, in the ordinary sense of the words, *i.e.*, the study of the structure, the mutual relations, and the arrangement or classification of plants and animals. But biology may also be pursued, and very profitably pursued too, quite independently of teachers, class-rooms, and examinations The country boy who knows the song of every bird, its nesting place, the number of its eggs, the nature of its food the lurking place of the trout in the stream or the frogs in the marsh ; who has watched the ants with their burden of grain, or the bees with their loads of honey or pollen ; has begun the study of biology in one of its most important branches. The intelligent gardener who observes the habits of plants, their individual tastes as to the soil, moisture, sunshine and the like, is also something of a biologist without knowing it. So also is the collector of eggs, shells, or insects, provided he honestly tries to learn all he can about the objects he collects, and does not consider them merely as a hoard or as objects for barter. Indeed, all that is often spoken of as natural history, so far as it deals with living things—plants and animals—and not with lifeless natural objects, such as rocks and minerals, is included under the head of biology.

What then is the connection between biology in this wide sense and the kind of thing you are expected to learn in a limited number of lessons ? Simply this :—In the class-room nature cannot be studied under her broader aspects : indeed, much out-door natural history cannot be *taught* at all, but must be picked up by those who have a love of the subject, a keen eye and patience. But there is one thing we can do within the narrow limits of the class-room : we can confine ourselves to some department of biology small enough to be manageable : we can take, for instance, one or more familiar animals and plants, and, by studying them in some

detail, get some kind of conception of animals and plants as a whole. This book deals with the zoological side of biology only ; and what we have now to do is, in fact, what you have often done in the study of English : you take a single verse of a poem at a time, analyse it, parse it, criticise its construction, try to get at its exact meaning If you have any real love of literature this detailed study of the part will not blind you to the beauty of the whole. And so if you have any real love of nature, the somewhat dry and detailed study we have now to enter upon should serve to awaken your interests in the broader aspects of biology by showing you, in a few instances, what wonderful and complex things animals are.

One word of warning before we begin work. You must at the outset disabuse your mind of the fatal error that zoology or any other branch of natural science can be learnt from books alone In the study of languages the subject-matter is furnished by the words, phrases, and sentences of the language ; in mathematics, by the figures or other symbols. All these are found in books, and, as languages and mathematics are commonly the chief subjects studied at school, they tend to produce the habit of looking upon books as authorities to which a final appeal may be made in disputed questions But in natural science the subject-matter is furnished by the facts and phenomena of nature ; and the chief educational benefit of the study of science is that it sends the student direct to nature, and teaches him that a statement is to be tested, not by an appeal to the authority of a teacher or of a book, but by careful and repeated observation and experiment.

The object of this book, therefore, is not only to give you some idea of what animals are, but also to induce you to verify the statements contained in it for your-

self. The description of each animal you should follow with the animal before you ; and if you find the account in the book does not agree with what you see, you must conclude, not that there is something wrong with your subject, but either that the description is imperfect or erroneous, or that your observation is at fault and that the matter must be looked into again. In a word, zoology must be learnt by the personal examination of animals : a text-book is merely a guide-post, and all doubtful points must be decided by an appeal to the facts of nature.

It matters very little what animal we choose as a starting-point—a rabbit, a sparrow, or an earthworm—one will serve almost as well as another to bring out the essential nature of an animal, how it grows, how it is nourished, how it multiplies On the whole, one of the best subjects to begin with is a frog : partly because it is easily obtained, partly because its examination presents no difficulties which an intelligent student may not be expected to surmount by due exercise of patience.

Let us therefore begin our studies by catching a frog and placing it in a convenient position for examination, as, for instance, under an inverted glass bell-jar or even a large tumbler.

External Characters.—Notice, first of all, the short, broad *trunk*, passing insensibly in front into the flattened *head*—there being no trace of a neck—and ending behind without the least vestige of a tail : these constitute the *axial* parts of the animal. In the ordinary squatting position the back has a bend near the middle, producing a peculiar humped appearance. The head ends in front in a nearly semicircular *snout*, round the whole edge of which extends the huge slit-like *mouth*. On the top of fore-end of the snout are the two small *nostrils*, one on

the fingers spread out and directed forwards. In this position the innermost of the four fingers corresponds with our own index-finger, the frog having no thumb. The hind-limb, under similar circumstances, is bent into a sort of Z, the knee being directed forwards and the ankle-joint backwards. The toes are turned forwards, and the inner one, which is the smallest of all, corresponds with our own great toe.

Owing to the bent position of the limbs, we cannot very well, as in our own arms and legs, speak of their upper and lower ends. It is therefore customary to call the end of a limb, or of any division of a limb, which is nearest to the trunk, the *proximal* end, that which is furthest away the *distal* end Thus the proximal end of the fore-arm is the elbow region, the distal end of a digit is its tip

In the largest Indian Frog (*Rana tigrina*), which is common all over India and Ceylon, the whole body, including head, trunk, and limbs, is covered with a soft, slimy skin of a green or olive colour, irregularly mottled with dark spots of varying size on the upper or *dorsal* surface, and whitish on the under or *ventral* surface. The colouring is, however, not constant ; in a frog kept in the dark the black spots increase to such an extent that the whole animal becomes almost black, while if kept in full daylight a corresponding brightening of the tints takes place. Moreover, the spots and patches of brighter colour are very variable · if you examine a dozen specimens you will see at once that no two are alike in this respect. The skin on the dorsal surface shows longitudinal folds with a strong fold above the tympanum.

Sexual Characters.—As in so many of the more familiar animals there are two sexes of frogs, easily distinguished from one another. If you examine several of them you

will find that a certain number have on the palm of the hand, towards the inner side, a large swelling, rather like the ball of our own thumb, but much more prominent and of a black colour, especially at the breeding season. Frogs having this structure are males ; it is not present in the females. Moreover, the males among the commonest Indian type (*Rana tigrina*) are usually of a darker colour than the females, and on the ventral surface of the head possess loose folds of skin, one on each side of the throat, a little behind the articulation of the jaws. These allow the expansion of the underlying vocal sacs, which help to intensify the noise produced by the frog, familiarly known as the croak

Actions performed by the Living Frog.—Kept under suitable conditions a frog very soon shows *evidences of life.* If touched or otherwise alarmed it attempts to escape by making a series of vigorous leaps—suddenly extending the hind legs and jumping to a considerable height. Thrown into water it swims by powerful strokes of the hind-limbs. It has thus, like so many living things with which we are familiar, the power of *voluntary movement.*

If kept under observation for a sufficient time—weeks or months—it will be found that frogs *grow* until they reach a certain limit of size. Growth, in the case of the frog, is an increase in size and weight affecting all parts of the body, so that the proportions remain practically unaltered, and no new parts are added.

Careful observation shows that the throat is constantly rising and falling, and the nostrils opening and shutting. These movements, like the expansion and contraction of the human chest, are *respiratory* or breathing movements, and serve to pump air into and out of the lungs.

It requires frequent watching and sharp observation to see a frog *feed.* It lives upon insects, worms, slugs, and the like. Opening its mouth it suddenly darts out a

tolerably long, nearly colourless, and very sticky *tongue*; if the prey is a small insect, such as a fly, it adheres to the end, and the tongue is quickly drawn back into the mouth, the whole operation being performed with almost inconceivable rapidity.

Like other animals the frog discharges *waste matters* from its body. Its droppings or *fæces*, discharged from the vent, are black and semi-solid. From the same aperture, it expels periodically a quantity of clear fluid, the *urine*, which is perfectly clear and colourless, and contains little besides water.

Sometimes a frog will escape from confinement, leaving its damp box or vivarium for the warm, dry atmosphere of an ordinary room. When this happens the animal is usually found next morning dead and shrunken, and with its naturally moist skin dry and hard. From this it may be inferred that there is a constant *evaporation of water* from the skin, which, under ordinary circumstances, is checked by a damp atmosphere or by occasional immersion in water.

Hibernation.—In winter frogs bury themselves in damp places, and become sluggish, manifestations of life becoming hardly apparent until the following spring, when they emerge from their holes. In this way they escape the dangers of frost which would otherwise be fatal to them. This suspension of activity during winter is known as *hibernation*, or the winter-sleep.

Reproduction and Development.—If you examine a number of frogs towards the end of winter—about February—you will find that the full-grown females are distinguished from the males, not only by the absence of the pad on the hand, but by the swollen condition of the trunk, due to the interior being distended with *eggs*. After a time the eggs are laid, being passed out of the vent by hundreds; each is a little globular body about

$\frac{1}{12}$th inch in diameter, half black and half white, and surrounded by a sphere of clear jelly, by means of which the eggs adhere together in large irregular masses, the well-known "frog-spawn." As the eggs are laid, the male passes out of his body, also by the vent, a milky *spermatic substance* or *milt*, which gets access to the eggs and *impregnates* or *fertilises* them. Without impregnation they are incapable of developing.

Neither male nor female takes the slightest care of the eggs when once they are deposited and fertilised. They are simply left in the water unprotected in any way; and, naturally enough, the mortality among them during the course of development is very great, the majority being eaten or otherwise destroyed, and only a very small percentage coming to maturity.

The first noticeable change in the spawn is that the sphere of jelly surrounding each egg swells up so as to acquire several times the diameter of the enclosed egg The egg itself, or *embryo*, as it must now be called, gradually becomes entirely black, then elongates, and takes on the form of a little creature (Fig. 2, 1) with a large head, a short tail, and no limbs; which after wriggling about for a time, escapes from the jelly and fixes itself, by means of a sucker on the underside of its head, to a water-weed. Great numbers of these *tadpoles*, as the free-living immature young or *larvæ* of the frog are called, may be seen attached in this way. At first they are sluggish and do not feed, but, before long, they begin to swim actively by lashing movements of their tails, and to browse on the weeds. They are thus in the main vegetable-feeders, not carnivorous, like the adult frog. On each side of the head appear three little branched tufts or *gills*, which serve as respiratory organs (2, 2"), the tadpole, like a fish, breathing air which is dissolved in the water. After a while the gills begin to shrivel up

2. A large and a small pair of straight *dissecting-forceps*, the small pair should have a peg on one leg fitting into a hole on the other, to prevent the points crossing; the points should be roughened.

3. A large and a small, fine-pointed pair of dissecting *scissors*; the small pair for the more delicate work, and the large pair for coarser work and for cutting through bones For the latter purpose a pair of *bone-forceps* is useful, but is not necessary in the case of such a small animal as the frog.

4. A *seeker, i e.*, a blunt needle mounted in a handle

5. Three or four *probes*; a seeker or knitting needle, or a thin slip of whalebone will answer for some purposes, but the most generally useful form of probe is made by sticking the end of a hog's bristle into melted sealing wax, and immediately withdrawing it so as to affix a little knob or guard

6 An *anatomical blowpipe*, or, failing this, a piece of glass-tubing, 6 or 8 inches long, with one end drawn out in the flame until it is not more than $\frac{1}{16}$th to $\frac{1}{20}$th of an inch in diameter

7. An ordinary "*medicine-dropper*," or "feeder" of a self-feeding pen (see Fig 29), made of a piece of glass-tubing about three inches long, drawn out in the flame at one end, and thickened at the other so as to form a collar, over which an india-rubber cap—an ordinary non-perforated teat—is fixed This is useful for washing fine dissections, as well as for injecting

8. A *dissecting-dish* Get a common pie-dish, about 6 or 8 inches long, with rather low sides. Cut out a piece of cork-carpet or thick linoleum the size of the bottom of the dish, and a piece of sheet-lead of the same size, and fasten the two together by three or four ties of copper wire or strong thread Place this in the dish with the lead (which is simply to keep the cork-board from floating in water) downwards. *Or*, place a few strips of sheet lead in the bottom of the dish, and then pour in some melted paraffin-wax into which a little lamp-black has been stirred, so as to make a layer half an inch or more in thickness.

For larger animals than the frog, in addition to a larger dish, a *dissecting-board* will also be required. Get a piece of soft deal or pine about 18 inches × 11 inches and $\frac{3}{4}$ inch thick, and nail round its edge a strip of wood about $\frac{3}{4}$ inch × $\frac{1}{4}$ inch, so as to form a projecting rim

9. A *magnifying glass*. Any good pocket-lens or a common watchmaker's glass will answer the purpose. As it is often desirable to have both hands free while using the

lens, a stand of some kind is useful. One of the simplest is made by fixing a piece of ¼-inch brass-tubing, about 6 inches long, into a heavy block of wood, about 3 inches in diameter, and coiling round it, in a close spiral, one end of a piece of thick wire, which can be raised and lowered on the tube; leave 6 or 7 inches of the wire standing out at right angles, and bend the free end into a loop to carry the lens. *Or*, get a piece of narrow clock-spring, about 13 inches long, and rivet one end to the outside of the rim of a watchmaker's glass, and the other to a small piece of zinc or brass, on passing the spring round the head, the lens is kept in place at the eye without exertion.

10 Medium and small-sized *pins*. Large blanket pins are useful for fixing down larger animals.

11. A small *sponge* and a *duster*.

12. One or more *wide-mouthed bottles* or *jars*, containing a *preservative* in which to place your subjects after each day's work The most convenient preservative for the purpose in most cases is the fluid sold as *formaline*,[1] which can be diluted as it is wanted. For preserving your dissections from day to day, a 1 per cent. solution of formaline is strong enough in many cases—*i e.*, 1 cubic centimetre of formaline to 99 c.c. of water, or three-quarters of a dram of formaline to half a pint of water. For permanent preservation, a stronger solution—2 to 5 per cent, according to circumstances—should be used, or methylated spirit. If formaline is not available, use strong methylated spirit (*i e.*, about 90 per cent.) diluted with one-third of its bulk of water.

13. A plentiful supply of clean *water*.

14. An ounce or two of *chloroform*.

Rules to be Observed in Dissection.—Many of the parts and organs of animals are bound together by means of a substance known as "connective-tissue," and the main object of dissection is to tear away and remove this substance so as to separate the parts from one another.

The subject should be firmly fixed down in the dissecting-dish or on the dissecting-board by means of pins, inserted obliquely, so that they do not interfere with the dissection The dissecting-dish must always be used for finer dissections, which should be done *under water*; only just enough water being put into the dish to cover the dissection, which should be washed under the tap from time to time.

When dissecting a part keep it on the stretch, and avoid fingering it or damaging it with the forceps.

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[1] A 40 per cent. solution of the gas *formic aldehyde*.

Never remove anything until you know what you are removing. Dissect *along* and *not across* such structures as blood-vessels and nerves.

See that your instruments are kept clean and sharp, and never use the smaller scissors and scalpels for coarse work.

Drawing.—You should make a point of drawing as many of your preparations, as well as of the living animals, as possible: an accurate sketch, taken from nature, no matter how rough, is of more value in teaching observation and in impressing the facts on your memory than the examination and copying of more perfect drawings, made by others Anyone can soon learn to make sketches of this kind, even without having any previous knowledge of drawing.

Each sketch should be made to scale, and small objects should be enlarged several times; it is much easier to insert details in a large drawing than in a small one. Mark the scale against each drawing—*e g*, $\times$ 2, $\times \frac{1}{2}$

Using a rule and compasses, first sketch in an outline of the principal parts with a *hard* pencil; if your object is bilaterally symmetrical, draw a faint line down the middle of the paper and then sketch in one side first. When you have sketched in all the outlines correctly, go over them again with a softer pencil, so as to make them clear and distinct Do not attempt any shading unless you have some knowledge of drawing.

Then tint the various parts in different colours, using *very light* tints except for such structures as vessels and nerves. You should keep to the same colours for the corresponding organs or tissues in all the animals you examine: thus you might in all cases colour the alimentary canal yellow, the arteries red, the veins blue, glands brown, cartilage green, and so on.

Make your drawings on one side of the page only; the opposite side can then be used for explanations of the figures.

Never insert on your original sketches anything you have not actually seen; you can copy as many other figures as you like from various sources, but these should be kept apart from your own original drawings.

Directions for the examination of the external characters of the adult frog, as described in this chapter, are given at the end of Chapter II., p. 31; and of the eggs and tadpoles in Chapter XII.

CHAPTER II

THE FROG (*continued*): GENERAL INTERNAL STRUCTURE

YOU have now seen that a frog can perform a number of very complicated actions; and, if you have any curiosity in these matters, you will probably want to know something of the mechanism by which these actions are brought about. Now, the best way to understand the construction of a machine, such as a clock or a steam-engine, is to begin by taking it to pieces; and, in the same way, you can find out the parts of which the living machine we call a frog is made, and the way they are related to one another, only by taking it to pieces, or *dissecting* it.

First notice, in addition to the external characters described in the last chapter, that the various parts of the body are strengthened or stiffened, as in ourselves, by a number of *bones,* which together form the greater part of the *skeleton.* It is quite easy to ascertain by feeling that the head contains a hard *skull;* the lower jaw, a lower-jaw-bone or *mandible;* that running through the back is a jointed backbone or *vertebral column;* that the region of the chest is protected by a breastbone or *sternum;* and that each division of the limbs has its own bone or bones.

The Mouth-cavity.—There are also several points to be observed in the interior of the mouth. All round the

edge of the upper jaw is a row of small conical *teeth* (Fig. 8). There are no teeth in the lower jaw; but on the roof of the mouth, a short distance behind the snout, are two little patches of teeth, called the *vomerine teeth* (*vo t*), and nearer the jaw are two apertures, called the *internal nostrils* (*p. na*): a guarded bristle passed into one of the external nostrils and pushed gently backwards and downwards will be found to enter the mouth by the corresponding internal nostril.

Behind the internal nostrils are two large hemispherical projections, due to the roof of the mouth being bulged out by the huge eyes, as can be readily made out by pushing the eyes from outside.

On the floor of the mouth is the large, flat *tongue* (*tng*), remarkable for the fact that it is attached at its front end, its hinder end being free and double-pointed. When the frog uses it to catch insects it is suddenly thrown forwards, almost like a released spring. The surface of the tongue being sticky, the prey is held fast and devoured as a whole, by the tongue being withdrawn, as quickly, back into the mouth-cavity. Just behind the backwardly-turned tips of the tongue is an oval elevation, having on its surface a longitudinal slit, called the *glottis* (*gl*), which leads, as we shall see afterwards, into the lungs.

The back of the mouth narrows considerably, and the soft skin or *mucous membrane* lining it is here thrown into folds. A probe gently pushed backwards passes, as we shall see, into the stomach. The narrowed region of the mouth is the throat, or *pharynx*. On its upper wall, near the angles of the mouth, are two pits: a guarded bristle passed into one of these will be found to come into contact with the corresponding tympanic membrane, which will be pierced if sufficient force is used. The pits are known as the *Eustachian recesses* or *tubes* (*eus. t*).

Dissection of the Frog: Skin and Muscles.—If a slit is made in the skin of the belly, and a probe pushed in under it, it will be seen that the skin, instead of being firmly attached to the underlying flesh, as in a rabbit or a sheep, is for the most part quite loose, a spacious cavity lying between it and the flesh. Not, however, a single continuous cavity for the whole body: the probe, gently pushed in various directions, is stopped, in front, at about the level of the arms; behind, at the junction of the thighs with the trunk; and at each side, along an oblique line joining the armpit with the thigh. Moreover, by opening the skin of the back, throat, and limbs, and inserting the probe as before, similar cavities will be found in these regions, all separated from one another by partitions, along which the skin is firmly united to the underlying flesh. It will be noticed also that the probe, when withdrawn from any of these cavities, is wet. The cavities contain a watery fluid, called *lymph*, and are hence known as *sub-cutaneous lymph-sinuses* (Fig. 8, *d. ly. s*, *v. ly. s*).

When the skin is removed it will be seen that under the skin and separated from it by the lymph-sinuses is a nearly colourless, semi-transparent, fibrous substance, the flesh. At first this appears to be continuous over the whole body, but, by careful dissection with a sharp scalpel, a very delicate, transparent skin, called the *fascia*, can be separated from the flesh, which is then seen to consist of a number of separate bands (Fig. 3, *my. hy*, *pct*, *rct. abd*; see also Fig. 19), covered as aforesaid by the fascia, and separated from one another by a kind of packing substance, also very delicate and transparent and known as *connective-tissue*. These bands or sheets are the *muscles*, and the whole of the flesh is made up of distinct muscles, readily separated from one another when once the requisite anatomical skill is attained.

turned forwards, and the abdominal vein (*abd v*) is severed and turned backwards. The right ovary and fat-body are removed, and the right oviduct (*r ovd*) is slightly displaced outwards (× 1½.)

abd. v abdominal vein, *cœl. mes* splanchnic or cœliaco-mesenteric artery, *cp. ad* corpus adiposum, or fat-body; *d ao* dorsal aorta; *gul* gullet, *hu* cut end of humerus or upper-arm bone; *l au* left auricle, *l lng* left lung, *l ovd* left oviduct, *l ovd'* its opening into the body-cavity; *l. ovd"*. its posterior dilatation, *l ovy* left ovary; *lr* portion of liver; *pt cv* postcaval vein, *pt cv'* its anterior portion passing between the liver and the heart; *r. au* right auricle; *rct* rectum, *r. kd* right kidney; *r. lng* right lung; *rn pt* renal portal vein; *r ovd* right oviduct, *r ovd'* its opening into the body-cavity, *r ovd"* its posterior dilatation; *syst tr* systemic arterial trunks at their point of union, *u bl* urinary bladder, *ur* ureter; *v* ventricle

cavity by a sheet of peritoneum. These bodies are the *ovaries*, or organs for the manufacture of the eggs; the rounded bodies of which they are largely composed are the *eggs* themselves. To each ovary is attached a yellow structure, produced into a number of streamer-like lobes (*cp. ad*); this is the *fat-body*, which serves as a storehouse of reserve nutriment.

By lifting up either of the ovaries there is seen beneath it—in the natural position of the parts, above or dorsal to it—a greatly convoluted colourless tube (*l. ovd, r. ovd*) of about the same diameter as the intestine. This is the *oviduct*, through which the eggs pass from the ovary to the cloaca. If the specimen is allowed to remain long in water the oviducts will be found to swell and finally to become disintegrated; this is due to the fact that in them is formed the jelly in which the laid eggs are enclosed, and which, as already mentioned (p. 10), swells in water.

In the male there is seen, on turning the intestines aside, a pair of yellow ovoidal bodies (Fig. 8, *ts*) about half an inch long, attached by peritoneum to the dorsal wall of the body-cavity. These are the *spermaries* or *testes;* they manufacture the spermatic substance or milt by which the eggs are impregnated. To the anterior end of each is attached a *fat-body* (*cp. ad*), like that of the female. In young specimens of both sexes the reproductive organs—spermaries, ovaries, and oviducts—are very small.

When the intestine is turned aside there will also be seen, in both sexes, a pair of flattened, irregularly-oval bodies (Figs. 5, *r. kd* and 8, *kd*) lying in the posterior part of the abdominal cavity just above or dorsal to the ovaries or spermaries. These are the *kidneys*. With the outer edge of each is connected a tube, the *ureter* (*ur*), by which the urine, formed in the kidneys, is carried to the cloaca (Fig. 8).

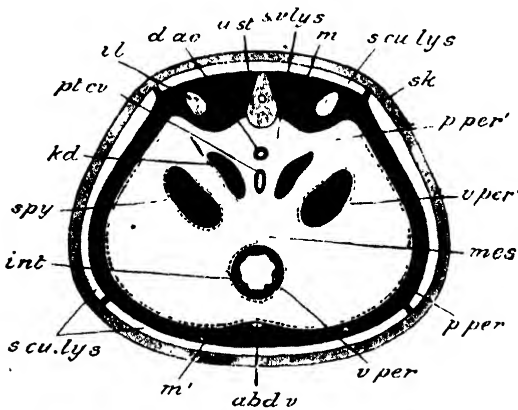

Fig. 6—Diagrammatic transverse section through the trunk of a Frog, to show the relations of the peritoneum (× 2½)
abd v. abdominal vein; *d ao* dorsal aorta, *il* ileum; *int* intestine; *kd* kidney; *m* muscles of back; *m'.* muscles of abdomen, *mes.* mesentery, *p per* parietal layer of peritoneum; *p. per'.* the same, turning down to cover the kidney, *pt cv.* postcaval vein; *sk* skin, *s. cu ly s.* sub-cutaneous lymph-sinuses, *spy.* spermary; *s. v. ly. s.* sub-vertebral lymph-sinus; *u st* urostyle (part of the vertebral column); *v. per.* visceral layer of peritoneum, investing intestine; *v per'* the same, investing spermary.

It has been pointed out that the abdomen is lined by peritoneum, and that the various organs are suspended by folds of the same membrane, called, in the case of the enteric canal, the mesentery. The relations of this membrane are best seen in a diagrammatic transverse section of the body (Fig. 6), though many points can be perfectly well made out from the actual

specimen. The body-cavity is lined by what is called the *parietal layer* of the peritoneum (*p. per*), which adheres closely to the body-wall except in the middle dorsal region, where it becomes closely applied to the ventral surface of the kidneys and reproductive organs Leaving these, the peritoneum of the right side approaches that of the left, and the two, coming into contact, form a double vertical sheet, the *mesentery* (*mes*), which extends ventrally towards the enteric canal. On reaching the latter, the two layers diverge again and surround the canal, forming the *visceral layer* of the peritoneum (*v. per*). The liver, oviducts, etc., are suspended and covered in the same way. Thus the lining of the body-cavity, the investment of the various organs contained in it, and the folds by which they are suspended, are all parts of one continuous membrane. The space left between the two diverging layers of peritoneum, in the mid-dorsal region, contains lymph, and is known as the *sub-vertebral lymph sinus* (*s. v. ly. s*).

We have already noticed the abdominal and musculo-cutaneous veins. Other veins of greater or less size will be seen everywhere, passing, for instance, to the head and limbs (Fig. 4), and in the mesentery. Running parallel with many of the veins are smaller vessels, many of which have pigment in their walls, and which are of distinctly stouter texture. These are the *arteries*. They contain little blood in the dead animal, and, owing to the stoutness and elasticity of their walls, do not collapse when empty. Hence they are quite easy to see in a frog from which all the blood has been drained, while the thin-walled veins are almost invisible under like circumstances. Finally, there will be seen in many parts of the body, often lying parallel to an artery and a vein-white cords, the *nerves*.

The Neural Cavity and its Contents.—By turning

the frog with its back upwards and cutting through the muscles of the back and the arches of the vertebræ as well as, in front, the roof of the skull (see Fig. 7), you will see that the backbone contains a distinct cavity, the *neural canal*, in which lies a white rod, made of the same

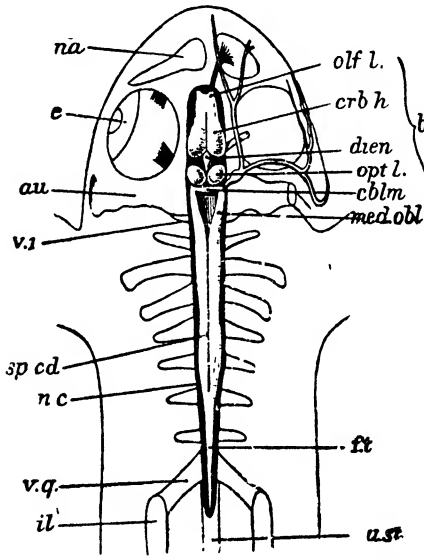

FIG 7.—Dissection of a Frog in which the entire neural canal (*n c*) has been opened from above, and the brain (*br*) and the spinal cord (*sp cd*) laid bare The brain consists of olfactory lobes (*olf l*), cerebral hemispheres (*crb h*), diencephalon (*dien*), optic lobes (*opt l*), cerebellum (*cblm*), and medulla oblongata (*med obl*), which will be referred to in Chapter X. The spinal cord ends in a delicate prolongation, the filum terminale (*f. t*). The nasal bones (*na*), eyes (*e*), auditory region of the skull (*au*), transverse processes of the nine vertebræ (*v 1—v 9*), urostyle (*u st*) and ilia (*il*) are indicated in outline, and serve as landmarks. (× 1½.) (After Howes, slightly altered)

soft kind of substance as the nerves, and called the *spinal cord* (*sp. cd*), which ends behind in a thread-like prolongation (*f. t*), some distance in front of the thighs. It will also be found that the neural canal is continued, with a slightly increased diameter, into the skull, and that the

vessels *organs of circulation*, serving as they do to propel and conduct the blood through the body; the kidneys, aided by the skin, *organs of excretion*, for getting rid of waste matters; the ovaries and spermaries, *organs of reproduction;* the muscles, *organs of movement;* the brain and spinal cord, together with the nerves, *organs of control*, serving to direct or control the actions of the body; the skin, nose, eye, and ear, *sensory organs*, by which communications are kept up with the external world.

Tissues.—Notice also that the various organs of the body are built up of different materials, or *tissues* as they are called. We have already distinguished muscle, bone, cartilage, connective-tissue and nervous tissue. Other tissues we shall meet with in the course of a more careful examination.

PRACTICAL DIRECTIONS

To Kill a Frog for Dissection.—Place a frog on a plate, and cover it with a tumbler, or put it into a stoppered bottle. Soak a little bit of cotton-wool or sponge in chloroform, and push it under the edge of the tumbler, or drop it into the bottle. In a few minutes the vapour will make the animal quite insensible, and a somewhat longer exposure will kill it painlessly.

External Characters.—Observe the voluntary and the involuntary respiratory movements of the living animal, and compare with a dead frog when making out the external characters (pp. 4–8) and the position of the various parts of the skeleton (p. 16).

Sketch the entire animal from the side or from above.

The Cavity of the Mouth.—Gently open the mouth of a dead frog as wide as possible, and make out the points described on p. 17. Sketch.

The Body-wall.—Lay the frog on its back in the dissecting-dish, and fix it firmly by sticking pins through the skin of the arms and legs. With the forceps, held in the left

hand, pinch up the skin of the abdomen near the middle line between the thighs, and make a nick in it with the point of the scissors. Then, holding the edge of the hole thus made, with the forceps, pass in a probe and push it forwards as far as it will go without opposition. Note —

The *sub-cutaneous lymph-sinuses*, and the underlying *muscle*.

With the scissors extend the incision made in the skin of the belly forwards, in a straight line, to the lower jaw. Holding up the edge of the skin with the forceps, cut through, with a scalpel, the partitions between adjacent lymph-sinuses, so as to separate the whole of the skin of the ventral surface from the muscle; and, having done so, pin back the flaps, right and left (see Fig 3). Similar cuts should be made in the skin of the limbs and back Observe—

The *fascia*, the *muscles* of the body-wall, the *abdominal* and *musculo-cutaneous veins*, and the position of the *hyoid* (p 40), *sternum* (p. 50), *shoulder-girdle*, and pubic region of the *hip-girdle* (pp. 36 and 53).

The Abdomen and its Contents.—Pinch up the muscles on one side of the abdominal vein with the forceps, and make an incision in them by a single snip of the scissors. Then, holding the edge of the wound with the forceps, extend the cut forwards to the shoulder-girdle and backwards to the pubis. Keep the cut parallel to the abdominal vein, and be careful not to wound the latter. You will find that the incision thus made opens a large *body-cavity* or *cœlome*, in which a number of structures, the *abdominal viscera*, are contained. Note that the body-wall consists of three layers: (1) *skin*, (2) *muscles*, with their *fascia*, and (3) *peritoneum*.

So far, however, the cavity is not thoroughly opened. Lift up the side of the abdominal wall to which the abdominal vein is attached, and very carefully separate the vein by tearing through, with a needle or the point of a scalpel, the connective-tissue by which it is attached to the inner face of the muscles: *or*, in order to prevent the possibility of injuring the vein, cut through the muscles of the body-wall longitudinally on the other side of the abdominal vein, so as to leave a narrow strip of muscle attached to it. Then make two cross-cuts, starting from the anterior end of the longitudinal incision, and extending outwards towards the fore-limbs: take care not to injure the musculo-cutaneous veins, and pin back the two flaps into which the soft abdominal wall is now divided (Figs. 4 and 5). Next dissect

away the muscles covering the shoulder-girdle, so as to expose the bones: identify the bones called *coracoid* and *clavicle* (compare a skeleton and Fig. 14). With the strong scissors cut through these bones on either side as near as possible to the shoulder-joint then lift up the sternum and middle portions of the shoulder-girdle, and carefully dissect them away from the underlying parts.

Having thus exposed the whole of the abdominal cavity, pour just enough water into the dissecting-dish to cover the animal, first washing away any blood which may have escaped from cut vessels If your specimen is female, dissolve a little common salt in the proportion of 1 per cent. in the water (1 gramme to 100 c c), or mix it with about one-third of its bulk of methylated spirit, in order to prevent the excessive swelling of the oviducts (If, however, you wish to make out the blood-vessels in this specimen without injecting them, it is as well to defer putting water into the dish until a later stage of dissection)

Note—

1. The *peritoneum—parietal* and *visceral layers*

2. The *pericardium*, containing the *heart*. If not already opened, the pericardium should be slit through, so that the *auricles* and *ventricle* can be plainly seen. If the frog has been killed quite recently, you will be able to observe the *pulsation of the heart*.

3. The right and left lobes of the *liver*, and the *gall-bladder*.

4. The two *lungs* : if contracted, inflate with a blowpipe through the glottis

5 The *enteric* or *alimentary* canal, consisting of *gullet* or *œsophagus*, *stomach*, *small intestine* (*duodenum* and *ileum*), and *large intestine* or *rectum* communicating with the *cloaca*, which will be seen at a later stage, and which opens to the exterior by the vent.

6 The *mesentery*.

7. The *pancreas*.

8 The *spleen*.

9. The *urinary bladder*. If collapsed, insert a blowpipe into the vent and inflate. (You will very likely find some small parasitic flat-worms, called *Polystomum integerrinum*, in the bladder; each worm has a ring of suckers round the hinder end.)

10. In the male the *spermaries* and *fat-bodies*, and in the female the *ovaries*, *fat-bodies* and *oviducts*

11. The *kidneys* and *ureters*.

12. The mode of suspension of all these organs (p. 26), and the position of the *sub-vertebral lymph-sinus*. In order to understand clearly the relations of these parts, a thick transverse section should be made through another frog in the region of the kidneys and examined under water (compare Fig. 6).

Sketch the contents of the abdomen *in situ*

The Neural Cavity and its Contents.—Now turn the frog with its back upwards, and pin it firmly to the bottom of the dissecting-dish or to the dissecting-board as before. Pinch up the skin, make a longitudinal cut through it from the snout to within a short distance of the vent, and turn the flaps right and left The muscles of the back will be exposed, and, in front, the roof of the skull, which lies just beneath the skin Carefully dissect away the muscles along the middle line of the back until the vertebral column is seen. Compare a prepared skeleton and Fig 9, and make out the arches of the vertebræ. Between the first of these and the back of the skull is a slight space insert one blade of the strong scissors into this, directing the point backwards, and cut through the arch of the first vertebra, first on one, then on the other side, and finally detach and remove the little piece of bone. The *neural canal* will then be exposed, in which lies the *spinal cord*, ending behind in a thread-like prolongation (compare Fig. 7). work backwards, cutting away the arches of the remaining vertebræ

Next, using the scissors in the same manner, cut away, bit by bit, the roof of the skull: two large bones—the *fronto-parietals* (see Fig. 10), forming a considerable part of the roof, can be more easily removed by raising them up with the edge of a scalpel. Note the *cavity of the skull* and its contained *brain*.

General Structure of the Limbs.—With a strong knife, cut across one of the legs at about the middle of the thigh. Compare p. 29, and notice the thigh-bone, muscles, and skin. Sketch.

Now preserve your specimen in formaline (about 2 per cent.) or spirit (70 per cent.).

CHAPTER III

THE FROG (*continued*): THE SKELETON

If you have followed the description given in the preceding chapter with a frog before you, testing every statement as you proceeded by reference to the specimen, you will now have a very fair notion of the general build of the animal. The next thing to do is to study its various parts in somewhat greater detail.

As the bones and cartilages form the framework on which all the other parts are supported, it is convenient to begin with them. You may study them on a prepared skeleton, but a far better plan is to make a skeleton for yourself as directed on p. 56.

Parts of the Skeleton.—The skeleton consists of the following regions:—

1. *The skull* (Figs. 10 and 11): a complex mass of mingled bone and cartilage, enclosing the brain and the organs of smell and hearing, and supporting the upper jaw. Connected loosely with the skull, but really forming part of it, are the lower jaw and a cartilage in the floor of the mouth known as the *hyoid*.

2. The *vertebral column* or *backbone*, consisting of nine movably united pieces, the *vertebræ* (Fig. 9, V.1—V.9), and of a long bony rod, the *urostyle* (UST), representing a number of fused vertebræ belonging to the tail-region of the tadpole.

3. The *shoulder-girdle* or *pectoral arch* (Figs. 13 and 14), an inverted arch of bone and cartilage nearly encircling the anterior part of the trunk and giving attachment to—

4. The bones of the *fore-limbs* (Fig. 16).

5. The *hip-girdle* or *pelvic arch* (Figs. 9 and 17), an apparatus shaped somewhat like a bird's "merry-thought": it is attached in front to the ninth vertebra and behind gives attachment to—

6. The bones of the *hind-limbs* (Fig. 9).

The Vertebral Column.—The essential structure of a vertebra may be best studied by examining any of the nine from the second to the seventh: the first, eighth, and ninth present certain peculiarities, and so may be left till last.

The whole vertebra (Fig. 9, B) has something the form of a signet-ring with its sides produced into two outstanding projections The part comparable to the stone of the ring is ventral in position, and is called the *body* or *centrum* (*cn*), the form of which is *procœlous, i.e.*, its anterior face is concave, its posterior face convex, and both faces are covered with a thin layer of cartilage. The part corresponding with the circle of the ring is the *neural arch* (*pd, lm*): it arches over the spinal cord and is produced in the middle line above into a blunt projection, the *neural spine* (*n. sp*). From the arch is given off, on either side, the large outstanding projection already referred to, the *transverse process* (*tr. pr*), which is tipped with cartilage. These cartilaginous epiphyses found upon the distal ends of transverse processes are particularly noticeable in *R. tigrina*, those upon the third vertebra being very large and backwardly directed.

The neural arch gives off from its anterior face, just above the origin of the transverse processes, a pair of small shelf-like projections, the *articular processes* or *zygapophyses* (*a. zyg*). Each has its upper surface flat

with this, the ninth (v. 9) has its centrum convex in front, while behind it presents two little rounded elevations placed side by side.

It will be seen that the vertebræ are all corresponding structures, following one another in a regular series from before backwards. A correspondence of this kind, in which there is a repetition of similar parts along the body, is termed a *serial homology*, and thus not only the vertebræ as a whole, but also their various parts are serially homologous, each to each, the correspondence being disturbed only by the first vertebra, in which the transverse processes are absent and the anterior face is modified for articulation with the skull.

The urostyle (UST) is a long bone with a gradually diminishing ridge along its dorsal surface (see p. 35) Its anterior face has somewhat the appearance of a small vertebra with no transverse processes, and has a double concavity for articulation with the double convexity on the ninth vertebra. Some distance behind the anterior end there is on each side a small aperture, representing an intervertebral foramen, for the last spinal nerve. These foramina are very imperfectly developed, and sometimes absent on one or both sides of the urostyle in *R. tigrina*.

The **skull** is a very complex structure, consisting partly of bone, partly of cartilage. It is divided into the following regions :—

1. The *brain-case* or *cranium*, a sort of oblong box containing the brain (Figs. 10 and 11): it forms the middle portion of the skull and is a direct forward continuation of the vertebral column.

2. The *auditory capsules*, a pair of outstanding masses arising, right and left, from the posterior end of the brain-case. They lodge the organs of hearing.

3. The *olfactory capsules*, smaller masses proceeding from the anterior part of the brain-case and united

with one another in the middle line. They lodge the organs of smell.

4. The *suspensoria* (*q*), a pair of projections springing from the outer and upper portions of the auditory capsules, and directed downwards, outwards and backwards. To them the ends of the lower jaw are attached.

5. The *upper jaw*, a half-circle of bone and cartilage, united in front to the olfactory capsules and behind to the suspensoria. On either side of the skull, between the cranium and upper jaw, is a large space, the *orbit*, in which the eye is contained.

6. The *lower jaw*, a roughly semicircular bar of bone and cartilage, articulated at its ends with the suspensoria.

7. The *hyoid* (Fig. 8, *b. hy*), a shield-shaped cartilage connected by delicate curved rods with the auditory capsules.

On the posterior surface of the brain-case is a large hole, the *foramen magnum* (Fig. 10, A), on either side of the lower edge of which is a large oval elevation covered with cartilage, the *occipital condyle*. The foramen magnum leads into the cavity in which the brain is contained. If the first vertebra is placed in its natural position with regard to the skull it will be seen that the foramen magnum corresponds with the neural canal of the vertebra, and that the condyles fit into its articular surfaces. Thus the skull readily moves up and down upon the vertebra, the condyles acting as rockers; a space between the neural arch and the dorsal edge of the foramen magnum covered by membrane in the fresh state allows of the requisite amount of play.

The discrimination of the separate bones and detailed structure of the skull is rather difficult, and may very well be omitted by the beginner at the present stage.

The occipital condyles are borne on a pair of irregular

to a small, slender bone, the *quadrato-jugal* (*qj*), which is firmly connected with the lower end of the suspensorium. Both premaxilla and maxilla are produced below into a prominent edge from which spring a number of small conical teeth, arranged in a single row.

Besides these three bones there are two others which seem, as it were, to brace the upper jaw to the brain-case and suspensorium. The *palatine* (*p*) is a narrow, rod-like bone, placed transversely behind the olfactory capsule. The *pterygoid* (*pt*) is a large three-rayed bone; one ray is directed forward and connected with the outer end of the palatine and with the inner face of the maxilla; another passes backwards and inwards and is connected with the auditory capsule; the third extends backwards and outwards and forms the inner and ventral portion of the suspensorium. The main mass or core of the suspensorium, between the squamosal outside and the pterygoid within, is a rod of cartilage (*q*), which is continued forwards by a bar (*pc*, *pq b*) supporting the pterygoid and palatine.

There is an important distinction to be drawn between the bones of the skull which can be made out only by the exercise of a good deal of care and patience. By softening the connective-tissue which binds the bones together, it is possible to remove the majority of them without injuring the underlying cartilage (compare Fig. 11, A), provided, of course, that the operation is skilfully performed: these bones are the nasals, vomers, fronto-parietals, parasphenoid, pre-maxillæ, maxillæ, quadrato-jugals, palatines, pterygoids, and squamosals. A sort of foundation or groundwork is then left behind, consisting mainly of cartilage, but containing the exoccipitals, pro-otics, and girdle-bone. These five bones cannot be removed without pulling the cartilaginous groundwork or *chondrocranium* to pieces. We thus get a distinction between *replacing bones* ("*cartilage bones*") which are actually continuous with the cartilage and form part of the chondrocranium, and *investing bones* ("*membrane bones*") which lie outside the chondrocranium, united to it only by connective-tissue.

The chondrocranium has a cartilaginous roof, underlying the fronto-parietals; it is pierced by one large (Fig. 11, A *f*) space, called the *fontanelle*, covered by membrane. It has also a cartilaginous floor (Fig. 10, B) underlaid by the parasphenoid. The olfactory capsules also have a cartilaginous roof and floor of irregular form, with the posterior end of which is united the cartilaginous *palato-quad-*

rate bar (*pc*, *pq b*), with which the palatine and pterygoid bones are connected. Posteriorly this bar is continuous with the cartilaginous groundwork (*quadrate*) or core of the suspensorium (*q*), which unites above with the auditory capsule and below furnishes an articular surface for the lower jaw.

Notice that in describing the vertebral column no distinction was drawn between replacing and investing bones As a matter of fact the vertebræ and the urostyle are all replacing bones ; each consists, in the tadpole, of cartilage which subsequently undergoes *ossification*, *i e.*, is replaced by bone in which a deposition of lime salts takes place.

The **lower jaw** consists of two halves, or *rami*, united with one another in front by ligament. At its posterior end each half bears on its upper surface a shallow pit, by which it articulates with the suspensorium, and a little in advance of this pit is an elevation of the dorsal edge of the jaw, called the *coronary process*.

Each half of the lower jaw consists of a cartilaginous core, the *mandibular* or *Meckel's cartilage*, which furnishes the articular surface referred to, and in front is ossified as a small replacing bone, the *mento-meckelian*. Outside the cartilage are two investing bones One, the *angulo-splenial*, extends along the inner surface and lower edge of the jaw and forms the coronary process, while the *dentary* forms the outer surface of the anterior half of the jaw

A feature worth noticing is the presence of three well-marked depressions on the ventral side of the upper jaw in its anterior portion. The middle one of these depressions is between the two premaxillæ and receives a corresponding median projection from the mento-meckelians. The two lateral depressions are at the junction of the premaxilla with the maxilla of each side and accommodate a strongly developed projection of the dentary of each side.

The **hyoid** is a thin, shield-shaped plate of cartilage (Fig. 8, *b. hy*) produced, both in front and behind, into a pair of processes or *horns*, as well as into less important offshoots. The *anterior horns* are long, delicate, cartilaginous rods which curve backwards and then upwards, finally joining with the audi-

of six small irregular bones, arranged in two rows (Fig. 16). The proximal row articulates with the radio-ulna, while to the distal row are attached the *metacarpals*, which together constitute the *metacarpus*. Four of these are long, rod-like bones and support the bases of the four fingers or digits: to them are attached the phalanges, of which the first or innermost digit (II) has two, the next two, and the remaining two digits three apiece. A very small metacarpal, with a single phalanx (I), occurs on the radial side and is concealed by the skin in the entire frog: it corresponds with our own thumb, so that the apparent first digit of the frog is really the second or index finger.

The Hip-girdle.—This, as we have seen, has somewhat the form of a bird's merrythought. It consists of two long arms (Fig. 9, IL; Fig. 17, *Il*), which are articulated with the transverse processes of the ninth vertebra, and sweeping backwards, unite in a disc-shaped mass, having on either side of it a deep, hemispherical cavity, the *acetabulum* (Fig. 9, *actb*; Fig. 17, *G*), for the articulation of the thigh-bone.

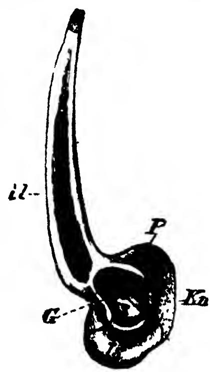

FIG. 17.—The hip-girdle of a Frog seen from the right side. (× 2.) *G.* acetabulum; *Kn* pubis; *Il*, *P* ilium, *Is* ischium (From Wiedersheim's *Comparative Anatomy*.)

Two *sutures*, or lines of separation, nearly at right angles to one another, divide the disc-shaped portion into three parts. One of these, dorsal and anterior in position, is continued into one of the arms of the hip-girdle and forms half of the acetabulum; this is the *ilium* (Fig. 17, *Il*, *P*). The second, posterior in position, is the *ischium* (*Is*); like the ilium it is made of true bone.

The third, or *pubis* (*Kn*), is ventral, and is formed of calcified cartilage. Originally each of these elements is paired, *i.e.*, there is an ilium, an ischium, and a pubis on either side, the three together forming the *innominate;* but in the adult the right and left ischia and pubes become united in the median plane, the ilia only remaining free.

The Hind-limb—The thigh, like the upper arm, is supported by a single long bone, the *femur* (Fig. 9, FE., Fig. 15, C), having a gently curved shaft and extremities of calcified cartilage. Its rounded proximal extremity, or *head*, fits into the acetabulum: its distal end articulates with the single bone of the shank, the *tibio-fibula* (TI. FI). This, the longest bone in the body, also has a shaft and extremities, and is further distinguished by grooves running from each end towards the middle of the shaft. Sections show that the grooved portions of the bone contain a double marrow-cavity (Fig. 15, D), and in the young animal there are found two shank-bones which afterwards unite, the *tibia* on the inner side, the *fibula* on the outer side.

The foot, like the hand, is divisible into three regions: the *tarsus* or ankle, the *metatarsus* or mid-foot, and the *phalanges* or toe-bones. The tarsus, like the carpus, consists of two rows, but with only two bones in each: Those of the proximal row (*astragalus* and *calcaneum*) are greatly elongated (AST., CAL.), and furnish an additional segment to the limb, thus increasing the frog's leaping powers: those of the distal row are very small.

The metatarsals are five in number: those of the first and second digits (I, II) bear two phalanges each, those of the third and fifth, three each, and that of the fourth, four. Attached to the inner side of the tarsus is a little claw-like structure (C) composed of two or three bones and called the *calcar* or spur.

Notice the striking correspondence in structure between the fore- and hind-limbs, a correspondence which extends also, though less obviously, to the limb-girdles. The humerus corresponds or is serially homologous (p 39) with the femur, the radius with the tibia, the ulna with the fibula, the carpals with the tarsals, the metacarpals with the metatarsals, and the phalanges of the fingers with those of the toes. Then in the limb-girdles the glenoid cavity corresponds with the acetabulum, the scapula and supra-scapula (being above the articular cavity) with the ilium, the precoracoid and clavicle (being ventral and anterior in position) with the pubis, and the coracoid with the ischium. Thus not only are the limbs and limb-girdles serially homologous structures, but their several parts are also serially homologous, each to each.

Nature of Bone.—It is a mistake to suppose that bones are made exclusively of hard mineral matter, like rocks or stones. If one of the long bones, for example, is put into weak acid, bubbles of gas will rise from the bone, showing that the phosphate and carbonate of lime, of which it is partly composed, is being decomposed with the liberation of carbonic acid gas. When the liberation of bubbles is over, the bone will be found to be unaltered in form, but to be quite flexible instead of hard and rigid. It can be bent in any direction, and a bone of sufficient length, such as a sheep's rib, can be tied in a knot. This shows that the bone contains a large amount of organic or animal matter. On the other hand, a bone may be completely *calcined* by heating to redness in a closed vessel, when its animal matter is completely consumed and its mineral matter left. Under these circumstances it becomes very brittle, falling to pieces at a touch, and its appearance is far more altered than by the removal of the mineral matter.

PRACTICAL DIRECTIONS

Preparation of the Skeleton.—Kill a frog with chloroform (p. 31), open the abdomen as directed on p. 32, but without cutting the shoulder-girdle, and remove the contained organs. Then, the frog being firmly pinned down, remove the skin and gradually cut away the flesh from the bones. In the case of the long bones of the limbs, it is best to cut through the muscles near one end of the bone and then gradually to strip them back towards the other end until the bone is exposed. The process is facilitated by dipping the frog occasionally into boiling water (maceration in cold water requires a considerable time): this softens the connective-tissue by which the bones and muscles are bound together, and thus allows them to be more readily separated. While at work keep Figs. 9, 10, 11, and 16 before you, and be particularly careful not to injure those parts of the skeleton which are made of *cartilage* (dotted in the figure), and are therefore easily cut: the most important of these parts are the *hyoid* or tongue-cartilage lying in the floor of the mouth, the *omosternum*, the *xiphisternum*, and the *supra-scapula* (Fig. 14). Great care will also be required in cleaning the bones of the hands and feet, since the fine cords or *tendons* which pass to them from the muscles are very strong, and if pulled upon with much force are sure to bring away the small toe-bones with them: they should be separated as far as possible and then cut off, close to the bones, with scissors.

Keep all the parts of the skeleton together, avoiding separation of the various bones, until the general characteristics of the entire skeleton have been made out: the only part which cannot be kept in connection with the rest is the shoulder-girdle, together with the fore-limbs.

Examination of the Skeleton.—You should have two skeletons to examine—one dried, after it has been thoroughly cleaned, and one which has been kept from the first in spirit or formaline: the latter is the more instructive (see also the *paraffin method*, p. 146). An additional skull should be carefully cleaned, and then boiled until the numerous bones become separated from one another or *disarticulated*.

After observing the form and relations of different parts of the skeleton as described on pp. 35 and 36 (Figs. 9–17), they may be separated from one another for more detailed examination. The individual vertebræ should be strung on a piece of wire or string so as to prevent them from being lost or misplaced.

With the specimen before you, work through the characters of the axial skeleton (pp. 36–48). If you omit the details given in small type at the present stage, do not forget to examine them subsequently. Make sketches of—*a*. any one of the vertebræ from the 2nd to the 7th, from the side and from the front or back; *b*. the 1st vertebra; *c* the last vertebra; *d*. the urostyle; *e*. the skull from above and from below; and *f*. the hyoid.

It requires considerable skill to make a satisfactory preparation of the chondrocranium, and it is advisable to examine that of a Dogfish first; but if you wish to attempt it, procure a large skull which has not been dried, and boil it in water. Carefully separate, by means of a scalpel, most of the *investing bones* (p. 45); the palatines, pterygoids and quadratojugals, and the dentaries and angulosplenials cannot well be disarticulated without destroying the soft cartilaginous parts beneath them.

Make out—1. The *brain-case* and its *fontanelles* and *nerve-apertures*. 2. The *olfactory capsules*. 3. The *auditory capsules*. 4. The *palatoquadrate bar* (to which the palatine, pterygoid, and quadratojugal bones have been left attached). 5. The *mandibular* or *Meckel's cartilage* (to which the angulosplenial and dentary have been left attached). 6. The *replacing bones* (*exoccipitals*, *pro-otics*, *sphenethmoid*, and *mento-meckelians*). 7. The *columella*, *stapes*, and *fenestra ovalis*.

Sketch from above and from below.

Now proceed to examine the appendicular skeleton (pp. 48–55), and sketch the shoulder-girdle and fore-limb, and the hip-girdle and hind-limb.

Split some of the longer limb-bones longitudinally with a knife, and note the *marrow-cavity* in the shaft (Fig. 15). Place another of the long bones in 10 per cent. hydrochloric acid for an hour or two; wash thoroughly in water and examine.

CHAPTER IV

THE FROG (*continued*): THE JOINTS AND MUSCLES

In the previous chapter the bones—more than 150 in number—which together constitute the greater part of the skeleton of a frog have been considered as so many separate parts, fitting into or against one another in certain ways. We must now see how they are joined together in the entire animal so as to afford the requisite support, and, at the same time, to allow of free movement.

The Hip-joint.—Let us begin by a study of the hip-joint (Fig. 18).

The acetabulum (*actb*), as you have already seen (p. 53), is a hemispherical depression on the outer surface of the hip-girdle. It is formed of cartilage, continued into a projecting rim round the edge of the cavity. The head of the femur (*hd*) is also formed of cartilage, and fits accurately but rather loosely in the acetabulum.

The acetabulum is lined, and the head of the femur is covered, by a thin layer of connective-tissue, the *perichondrium* (*p. chd*), which, in both cases, is continued on to the adjacent bone, where it receives the name of *periosteum* (*p. ost*).

Attached all round the rim of the acetabulum is a strong sheet of connective-tissue called the *capsular ligament* (*cps. lg*), forming a short, fibrous tube. The other

end of this tube is fixed to the femur, just below the head, the ligament being continuous, in each case, with the perichondrium. There is thus a space between the head of the thigh bone and the acetabulum, closed all round by the capsular ligament. This space is filled with a delicate, fibrous, closed bag, the *synovial capsule* (*sy. cps*), one side of which fits closely into the acetabulum, while the other as closely invests the head of the femur.

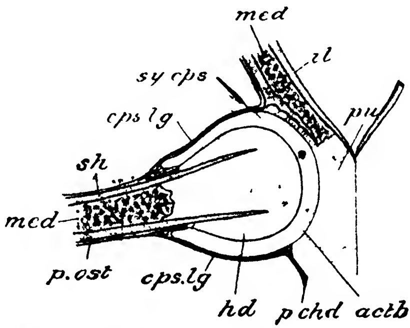

FIG. 18—Horizontal section of a Frog's hip-joint (× 5)
actb acetabulum, *cps lg* capsular ligament; *hd* head of femur, *il* ilium, *med* marrow, *p chd* perichondrium, *p ost* periosteum; *pu.* pubis; *sh* shaft of femur, *sy cps* synovial capsule

The capsule is filled with a watery fluid, the *synovia*, and thus forms a buffer or water-cushion between the adjacent parts of the skeleton. Thus the synovial capsule keeps the two parts slightly apart and prevents friction, while the capsular ligament keeps them together and prevents dislocation.

It is obvious that, in such a joint as this, movement is possible in all directions. The femur can be inclined either upwards, downwards, or sideways, and is capable of a certain amount of rotation. The joint is, in fact, a *cup-and-ball joint*, and is capable of movement in any plane. A similar but less perfect cup-and-ball joint is

that of the shoulder, in which the cup is furnished by the glenoid cavity, the ball by the head of the humerus.

Other Joints.—The elbow- and knee-joints are constructed on the same general plan, but, owing partly to the form of the adjacent surfaces, partly to the mode of attachment of the ligaments, they are capable of movement in one plane only, *i.e.*, up and down, but not from side to side. They are therefore distinguished as *hinge-joints*.

The vertebræ are connected with one another in a similar way. Between the convex hinder face of one centrum and the concave front face of its successor is a synovial capsule, and the two centra are bound together by ligament, a shallow cup-and-ball joint, with a very limited range of movement, being produced. There are also synovial capsules between the articular processes, which, being in contact with one another by flat surfaces and working mainly from side to side, form *gliding-joints*. Strong ligaments connect the neural arches with one another and join the first vertebra to the skull.

In all cases where free movement is necessary the joints are formed in the same way; the bones are bound together by ligaments, and a synovial capsule is interposed between their adjacent cartilage-covered surfaces. Where little or no movement is required, as between the bones of the shoulder- and hip-girdles, the union is effected by cartilage or ligament only, and there is no synovial capsule. Such joints are therefore distinguished as *immovable* or *imperfect joints*.

The Muscles.—We see then that the bones of the skeleton are attached to or articulated with one another by means of ligaments, so arranged, in most cases, as to allow of more or less free movement between the bones.

CHAPTER IV

THE FROG · NERVOUS SYSTEM AND SENSE ORGANS

Nervous System: General Arrangement.

In the nervous system of the frog there may be recognised two main parts—the *cerebro-spinal system*, connected with the organs of sense and the voluntary muscles, and the *sympathetic system*, connected with the viscera and blood vessels. The cerebro-spinal system comprises the *central nervous system or cerebro-spinal axis*, composed of the brain and the spinal cord, and the *peripheral nervous system*, containing the *cerebro-spinal nerves* and certain knots of nerve cells upon them, known as their *ganglia*. There are ten pairs of *cranial nerves* arising from the brain, and the same number of *spinal nerves* The sympathetic system also consists of nerves and ganglia.

Spinal Cord.

The spinal cord is an elongated, subcylindrical structure, lying in the vertebral canal of the backbone. It is somewhat flattened from above downward, tapers to a fine thread, the *filum terminale*, in the urostyle, and swells somewhat in the regions of the limbs. A transverse section (Fig. 60) reveals the fact that it is traversed by a *central canal*, which ends blindly behind, but in front is continuous with cavities in the brain. It is composed of nervous tissue enclosed in a connective tissue sheath, the *pia mater*, which, along the dorsal and ventral middle lines, passes in to some depth as the *dorsal and ventral fissures*. The nervous tissue is of two kinds, a *white matter* outside and a *grey matter* around the central canal. In transverse section the grey matter extends as *dorsal and ventral horns* on each side.

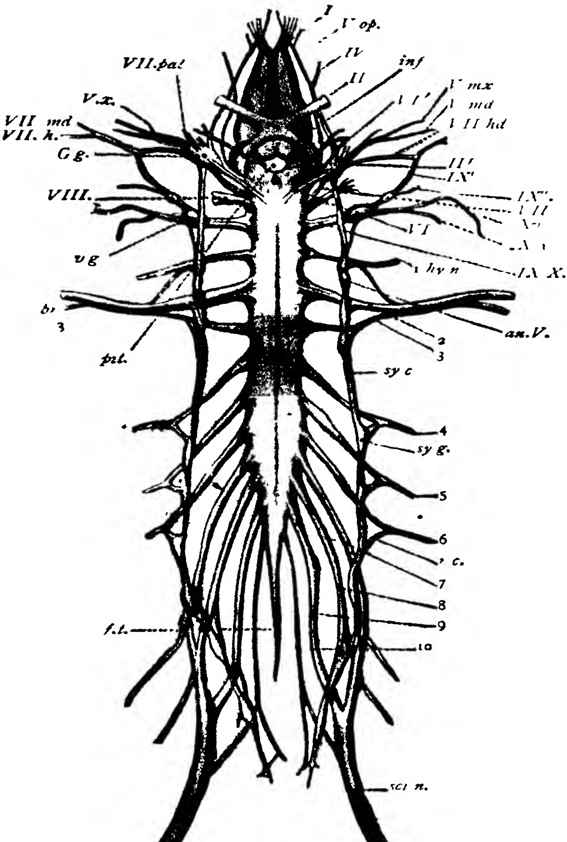

FIG. 39.—The central nervous system and principal nerves of a frog, seen from below —Partly after Ecker

I.–X, Cranial nerves, 1–10, spinal nerves; *V md*, *V mx*, *V op*, mandibular, maxillary, and ophthalmic branches of fifth cranial nerve, *V x*, a small twig from the undivided main branch of the same nerve, *VI'*, sixth cranial nerve after leaving the prootic ganglion, *VII h*, and *VII md*, hyoidean and mandibular branches of hyomandibular nerve, *VII hm*, *VII pal*, hyomandibular and palatine branches of seventh cranial nerve, *IX'*, branch from ninth cranial nerve to seventh, *IX''*, main branch of ninth cranial nerve, *X v*, tenth cranial nerve passing to viscera, *X x*, a branch from the vagus to certain muscles, *an V.*, annulus of Vieussens, through which the subclavian artery passes, *br*, brachial nerve [illegible] minale, *Gg*, Gasserian geniculate or prootic ganglion [illegible] (first spinal) nerve, *inf*, infundibulum, *pit*, pituitary [illegible] communicans, *sci n*, sciatic nerve, *sy c*, longitudinal commissure of sympathetic chain, *sy g*, sympathetic ganglion; *v g*, vagus ganglion.

Spinal Nerves

The ten pairs of spinal nerves pass out between the vertebræ to be distributed over the body. Each nerve is surrounded as it issues by a soft, white *calcareous concretion.* Every nerve arises by two *roots*, a dorsal and a ventral, and the dorsal root bears a small swelling, the *dorsal root ganglion.* Just outside the backbone the two roots join, and the nerve thus formed proceeds at once to divide, giving rise to (*a*) a short *dorsal branch* to the muscles and skin of the back, (*b*) a long and conspicuous *ventral branch* to the muscles and skin of the sides and ventral surface of the trunk, and in some cases to the limbs, and (*c*) a small *ramus communicans* to the sympathetic system. The dorsal root is also called *sensory or afferent* because along it impulses pass inwards to the spinal cord and produce, among other effects, sensation, and the ventral is called similarly *motor or efferent* because along it impulses pass outward and produce, among other effects, contraction of muscles. This is shown by the fact that cutting the dorsal root deprives of sensation the parts supplied by its nerve, while cutting the ventral root paralyses the same parts. Each of the branches contains elements derived from both dorsal and ventral roots. The course of the dorsal branches and rami communicantes is much the same in all cases, but that of the ventral branches differs greatly in different nerves and must now be followed.

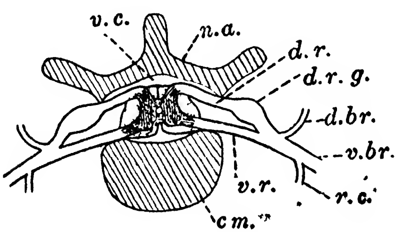

FIG. 40.—A diagram of the origin of the spinal nerves of the frog.

cm, Centrum, *d.br.*, dorsal branch of the nerve, *d r*, dorsal root, *d r g*, dorsal root ganglion, *n a*, neural arch, *r.c*, ramus communicans; *v br*, ventral branch; *v.c.*, vertebral canal, *v r*, ventral root

The *first spinal nerve*[1] is known as the *hypoglossal.*

[1] The nerve which is counted as the first spinal nerve in the frog is in reality the second. The true first spinal nerve, which should issue between the skull and the first vertebra, appears in the embryo, but is lost later on.

It leaves the neural canal between the first and second vertebræ, curves round the throat, turns forward below the mouth, and proceeds to the tongue. The *second spinal nerve* is a large strand running straight outwards. It receives branches from the first and third, forming thus the *brachial plexus*, and proceeds as the *brachial nerve* to the arm. The *third spinal nerve* is small, and beyond the brachial plexus resembles the *fourth, fifth, and sixth spinal nerves*. All these are small and run backwards to supply the muscles and skin of the belly. The *seventh, eighth, ninth, and tenth spinal nerves* join to form a *sciatic plexus*, from which arise several nerves to the hind-limb, the principal being the very large *sciatic nerve*. The tenth nerve leaves the vertebral canal by a foramen in the side of the urostyle. The roots of the last four pairs of nerves do not issue from the spinal canal at once, but run backwards for some distance from their origin to reach their point of exit. Thus they form inside the vertebral canal a bundle known as the *cauda equina*.

Brain. The brain may be divided into three regions, known respectively as the *hind, mid, and fore brains*. The hind-brain consists of the *medulla oblongata* and the *cerebellum*. The medulla oblongata is the hindermost part of the brain. It is continuous behind with the spinal cord, which, as it is traced into the brain, widens, the central canal enlarging into a cavity in the medulla known as the *fourth ventricle* of the brain, the ventral side thickening, and the dorsal thinning out into a slight membrane over the fourth ventricle (Fig. 26) The pia mater above this membrane is very vascular and thrown into folds which project into the ventricle, forming thus a structure known as the *posterior choroid plexus*. The cerebellum is a narrow band across the roof of the front part of the fourth ventricle. In many other animals it is relatively much larger. The *mid-brain* is the region in front of the medulla. It has a thick floor formed by two longitudinal columns known as the *crura or pedunculi cerebri*, a roof consisting of a pair of rounded swellings known as *optic lobes*, and internally a narrow passage, the *aquæductus cerebri*, continuous behind with the fourth ventricle and above with cavities in the optic lobes. The fore-brain consists of the *thalamen-*

cephalon and the *cerebral hemispheres* The thalamencephalon lies immediately in front of the mid-brain. Its sides are thick and are known as the *optic thalami*; its roof and floor are thin. The floor is prolonged into a hollow structure known as the *infundibulum*, to the end of which is applied a glandular, non-nervous mass called the *pituitary body or hypophysis* The roof is prolonged into a

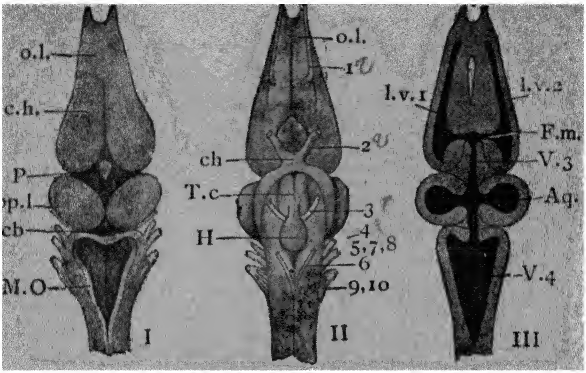

FIG. 31 —The brain of a frog.—After Wiedersheim.

I DORSAL ASPECT —*o l.*, Olfactory lobes, *c h*, cerebral hemispheres; [illegible]lk, rising from region of optic thalami, *op l*, optic [illegible]dimentary cerebellum; *M O*, medulla oblongata

II VENTRAL ASPECT —The numbers indicate the origins of the nerves *ch*, Optic chiasma, *T c*, tuber cinereum (infundibulum), *H*, pituitary body or hypophysis

III HORIZONTAL SECTION —*l v* 1 and 2, lateral ventricles of cerebrum, *F m*, foramen of Monro, *V* 3 and 4, third and fourth ventricles, *Aq*, cavities of optic lobes and aqueduct from third to fourth ventricle

short, hollow stalk, which in the tadpole is connected with a structure known as the *pineal body*. In the adult this has become separated and lies outside the skull. In certain other animals the pineal body is much more highly developed and still connected with its stalk, and its structure shows that it is the remnant of a middle eye, though it is no longer functional. In front of the pineal stalk lies an *anterior choroid plexus*. The cavity of the thalamencephalon is deep but narrow, and is known as the *third ventricle*. It is bounded in front by a wall known as

the *lamina terminalis*. Behind this on each side an opening known as the *foramen of Monro or foramen interventriculare* leads into the cavity or *lateral ventricle* of one of the cerebral hemispheres. These are oblong-oval bodies narrowing forwards to join a mass which is indistinctly separated into two *olfactory lobes*. The median walls of the cerebral hemispheres touch in front and behind, but for a considerable distance they are quite separate. The brain, like the spinal cord, contains both white and grey matter. In the medulla oblongata and optic lobes the grey matter lies mainly around the ventricles, but in the thalamencephalon, cerebral hemispheres, and olfactory lobes there is an outer grey layer or *cortex* over the white matter.

Cranial Nerves.[1]

The *first or olfactory cranial nerve* of each side arises from the olfactory lobe and runs forward to the olfactory organ in the nostril. The *second or optic nerve* starts from the side of the mid-brain, curves round underneath the brain, running forwards and inwards, and crosses its fellow below the thalamencephalon on its way to the eyeball of the opposite side. Where the nerves cross they are fused, and the X-shaped structure thus formed is called the *optic chiasma*.[2] The *third or oculomotor nerve* supplies the eye muscles, with the exception of the superior oblique and external rectus. The small *fourth, pathetic, or trochlear nerve* arises between the optic lobe and cerebellum and supplies the superior oblique muscle. It is the only nerve which starts from the dorsal surface of the brain. The large *fifth or trigeminal nerve* arises from the side of the anterior part of the medulla. Just before it passes through its foramen it bears a large swelling, the *Gasserian-geniculate or prootic ganglion*. It then divides at once into an *ophthalmic branch*, which runs forwards along the inner wall of the orbit and supplies the skin of the forepart of the head, and a *main branch*, which runs outwards across the hinder part of the orbit and divides into a *maxillary branch* to the upper jaw and a *mandibular*

[1] For the foramina by which the cranial nerves leave the skull, see p. 32. These nerves can more easily be dissected in the dogfish, where their course is substantially the same (see pp. 250–254).

[2] The crossing is not complete, part of each nerve proceeding in that limb of the X which passes to the eye of the same side.

upwards or towards the thigh, the foot will instantly be bent backwards, so as to come into a straight line with the shank, the action being one of those performed by the living frog when leaping. It will be seen that the proximal tendon is attached to a relatively fixed point: it is distinguished as the tendon of *origin*, or the muscle is said to *arise* from the ferum and tibio-fibula. The distal tendon is attached to a relatively movable part, the foot, and is called the tendon of *insertion*, the muscle being said to be *inserted* into the plantar fascia

Muscular Contraction.—Obviously, however, there is nothing to pull upon the muscle from outside in the living frog. We must, therefore, try to form some idea as to how the action of bending the foot, roughly imitated in the dead subject, is performed during life. If the gastrocnemius be exposed in a recently killed frog, the foot bent up as before, and a smart pinch be given to the belly of the gastrocnemius, the foot will be bent back, although no pull has been exerted on the muscle. The same thing will happen if you drop on the gastrocnemius a single drop of weak acid or of a strong solution of common salt, or if you touch it with a hot wire, or if you apply to it the electrodes from an induction coil so as to pass an electric current through it.

Careful observation shows that what happens under either of these circumstances is that the belly of the muscle decreases in length and at the same time increases in breadth, so as to become shorter and thicker (Fig. 20). The result of this must necessarily be to cause its two ends to approach one another. As the tendon of origin is attached to the femur, which we suppose to be fixed, it is unable to move, and the insertion is therefore drawn upwards, bringing with it the movably articulated foot. In fact exactly the same thing takes place as

when we raise our own fore-arm. This action is performed by means of the biceps muscle which arises from the scapula and is inserted into the fore-arm. When the latter is raised we feel a lump rise on the front of the upper arm due to the thickening of the biceps.

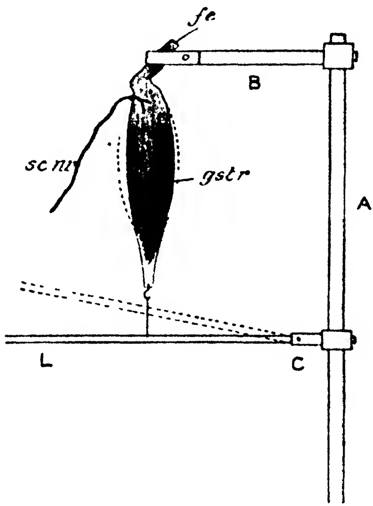

FIG 20 —Diagram of apparatus for demonstrating the contraction of the gastrocnemius muscle

A, upright, bearing two adjustable horizontal arms To the upper of these (B) is fixed by a clamp the femur (*fe*), having the gastrocnemius (*gstr*) in connection with it To the lower arm (C) is fixed a light lever (L) movable in a vertical plane, and having the tendon of insertion of the muscle attached to it by a thread. The dotted lines show the form of the gastrocnemius and the position of the lever during contraction of the muscle *sc nv* the sciatic nerve

This shortening and thickening of the muscle is termed a *contraction*. Do not fail to notice that this word is used in a special sense. When we say that a red-hot bar of iron contracts on cooling, we mean that it becomes smaller in all dimensions—undergoes an actual decrease in bulk But in muscular contraction there is no alteration in bulk . the decrease in length is

balanced by an increase in thickness, as when a stretched piece of india-rubber is relaxed.

The external influence by which a contraction is induced is called a *stimulus*. As we have seen, a stimulus may be produced by actual contact of some external object (*mechanical stimulus*), or by chemical action (*chemical stimulus*), or by heat (*thermal stimulus*), or by an electrical current (*electrical stimulus*).

Relation of Muscle and Nerve.—Evidently, however, we have by no means got to the bottom of the matter In the living frog movements are always going on, and all are due to the contraction of muscles, and yet no stimuli of the kind enumerated are applied to any of them. As the muscles retain the power of contraction for some little time after the death of the animal, it is easy to make such experiments as that described in the next paragraph.

Running longitudinally between the muscles on the dorsal side of the thigh is a shining, white cord, the *sciatic nerve* (Fig. 20, *sc.nv*), accompanied by an artery: it gives off branches to the muscles and skin, and, amongst others, one to the gastrocnemius. If, when quite fresh, this nerve be carefully separated as it traverses the thigh and pinched with the forceps, the gastrocnemius will contract just as if the stimulus had been applied to it directly, and the same will happen if a chemical, thermal, or electrical stimulus be applied.

Thus a stimulus applied to the nerve of a muscle has the same effect as if applied to the muscle directly: it gives rise to a *nervous impulse*, which, travelling along the nerve, induces contraction of the muscle.

Once more, however, external stimuli are not applied to the frog's nerves during life, and it is obvious that we must carry our inquiry a little further. The sciatic nerve if traced upwards will be found to pass into the

trunk (Fig. 56, *sci*), and finally to join the spinal cord, which, as we have seen, is in connection with the brain. In the living frog nervous impulses originate in the brain, without the direct intervention of an external stimulus, and are conducted along the cord and nerves to the muscles. But further consideration of this subject must be deferred until we have made a special study of the nervous system.

The Muscular System in General—All over the body the muscles, though varying greatly in form—some being elongated and band-like (Fig. 19, *sar*), others spindle-shaped (*gastr*), others in the form of broad, flat sheets (*my. hy, obl. ext*)—have the same general relation to the skeleton as in the case of the gastrocnemius. Each muscle arises or has its origin in a relatively fixed part, and is inserted into a relatively movable part. As each muscle contracts in one direction only, it follows that the more complex the movements any part is capable of performing, the more numerous must be its muscles. For instance, the femur, which, as we have seen, is capable of universal movement, has no fewer than nine muscles, arising from various parts of the hip-girdle, inserted into it. Even the minute phalanges of the fingers and toes all have their little slips of muscle by which the various movements of grasping and relaxing, approximating and separating the digits, are effected.

There are certain terms applied to muscles which it is useful to know. A muscle which raises a part, *e g*, the lower jaw, is called a *levator*, one which lowers a part a *depressor*. A muscle which serves to straighten one part upon another, *e g.*, to bring the shank into line with the thigh, is an *extensor*, one which bends one part on another is a *flexor*. A muscle which draws, *e g.*, a limb towards the trunk is an *adductor*, one which draws it away an *abductor*, one which rotates one part upon another (*e.g*, the femur on the pelvis), a *rotator*

Thus all the complex and accurately adjusted movements of the frog are performed by the contraction of its numerous muscles, acting either singly or in concert. The contractions of these muscles are brought about by nervous impulses sent from the brain or spinal cord along nerves which branch out and are distributed to the muscles, thus bringing the whole of the complex machinery which affects the movements of the animal under the direct control of its will.

PRACTICAL DIRECTIONS

The Joints and Ligaments.

1 The *hip-joint* Strip off most of the muscles from the thigh and the adjacent parts of the pelvis ; decalcify in weak acid and then wash thoroughly. Cut the femur through lengthwise and continue the section through the pelvic girdle (Fig 18) The details are more easily made out if the femur of a larger animal (*e g* , rabbit) be used

Note *a* The *cartilage* of the acetabulum and head of the femur ; the *perichondrium* and *periosteum* *b* The *capsular ligament* and its relations to the *synovial capsule.* Observe that the hip-joint is a *cup-and-ball* joint Sketch

In a prepared wet skeleton—

2. Examine and compare a *hinge-joint* (*e.g* , elbow or knee).

3 Examine the cartilaginous union between the bones of the shoulder- or hip-girdle (*immovable* or *imperfect* joints).

4 Examine the joints and ligaments of the vertebral column

The Muscles.

1. Remove the skin from part of the body and legs of a preserved frog (the one you have already dissected will do) Then clear away the fascia here and there and separate some of the muscles by dissecting away the connective-tissue which binds them together. Notice the different forms of the muscles in different parts (Fig. 19 and p. 66).

2. In the hind-leg carefully dissect away the connective-tissue investing the *gastrocnemius* muscle (Figs. 19 and 20), and trace it upwards towards the thigh and downwards

towards the foot, cutting away any of the other muscles which obscure the view. Notice the *belly*, and the tendons of *origin and insertion* (p. 63). Sketch.

Bend the foot upon the shank as in the ordinary sitting position of the frog. Hold the thigh firmly with one hand, and with the other take hold of the gastrocnemius and pull it upwards or towards the thigh. Note the result

3. In a quite freshly killed frog (see p. 109) expose the gastrocnemius as directed above, and with the small forceps give a sharp pinch to the belly of the muscle. Note the *contraction* following the *stimulus*.

Then remove the skin on the dorsal side of the thigh, and separate the muscles in this region so as to expose the *sciatic nerve* (Figs. 20 and 56). Trace this towards the shank and notice its branch going to the gastrocnemius. Carefully separate the nerve as it traverses the thigh and pinch it with the forceps, noting again the contraction following the stimulus.

CHAPTER V

THE FROG (*continued*): WASTE AND REPAIR OF SUBSTANCE —THE DIGESTIVE ORGANS—NUTRITION

Waste and Repair.—The effects of prolonged muscular exertion are familiar to everyone. Sooner or later sensations of fatigue, hunger, and thirst are produced, accompanied by a loss of weight. Indeed, however little exertion we make and however often we feed, our weight always goes down between meals and rises again when we take food. The loss of substance, of which the diminution in weight is the index, takes place largely in the form of perspiration, a fluid consisting of water with certain organic and inorganic matters in solution. A further loss is due to the air breathed out from the lungs; this is always moist, *i.e.*, contains a good deal of water, and is further distinguished by containing a considerable volume of carbonic acid gas or *carbon dioxide* (CO_2). Besides these two constant sources of loss, there is an intermittent loss in the urine, which consists of water containing certain matters in solution, the most characteristic of which are two complex substances called urea (CON_2H_4) and uric acid ($C_5H_4N_4O_3$). Both of these, as well as carbon dioxide, act as poisons if allowed to remain in the system. Lastly there is an intermittent source of loss in the waste matters or fæces which are passed out from the intestine.

These losses are made good in two ways. Firstly, by breathing, in which process we constantly inhale pure air and replace the poisonous carbon dioxide by oxygen. Secondly, by eating and drinking, by which, at intervals, we make good the loss of solids and liquids. Just as a clock is constantly running down and has to be wound up in order to keep it going, so our bodies run down by loss of substance between meals, and require to be wound up by the repair of substance which results from food and drink.

The same thing is true of the frog. Every one of its numerous and often vigorous movements is done at the expense of a certain waste of substance. The various tissues of the body are constantly undergoing a process of wear and tear, expressed not as in machines of human construction, by a wearing away of surfaces and a loosening of bolts and screws, but by a slow and almost imperceptible dwindling, the lost material being carried off principally in the form of water, carbon dioxide, and urea or some allied compound containing nitrogen.

Food of the Frog: general characteristics of the Digestive Process.—As we have seen, the food of the frog consists of worms, slugs, insects, and the like. These it catches and swallows whole, the stomach often becoming immensely distended with numbers of captured animals. After remaining for some time in the stomach the carcases are found to have undergone a marked change. Their soft parts become softer and slimy and finally semi-fluid, and in this way the food undergoes gradual disintegration. The quantity of food in the stomach decreases, some of it is passed into the intestine, which it traverses from duodenum to rectum, and certain portions of it are finally ejected from the vent in the form of fæces.

It is not difficult to assure one's self that the weight of the fæces passed during a certain time is very much less than that of the food swallowed during the same time. Obviously some constituents of the food have disappeared during its progress through the enteric canal. The character of the fæcal matter, moreover, is very different from that of the food; the only portions of the swallowed animals discoverable in the rectum are bits of their hard parts; for the rest, the fæces form a pulpy, black mass. That this change is due to certain definite chemical processes taking place in the enteric canal may be inferred from the fact that the contents of the stomach, as well as the walls of that organ, have an acid reaction, and turn blue litmus paper red. On the other hand, the contents of the small intestine are, to a greater or less extent, alkaline, restoring reddened litmus paper to its original blue colour.

It is also obvious that there must be some definite mechanism for propelling the food from one end of the enteric canal to the other; its passage through so long, narrow, and coiled a tube can certainly not be accounted for by supposing it to be merely pushed onwards as fresh food is swallowed.

In order to understand the various processes connected with digestion we must make a renewed and more careful examination of the organs concerned.

The Digestive Organs.—By cutting open the enteric canal and examining its inner surface under water with a magnifying glass, it is seen that the wall of the canal consists of two layers, easily separable from one another. The outer or *muscular layer* (Fig. 22, A, *musc*), covered by the peritoneum (p. 26), is tough and strong, the inner layer or *mucous membrane* (*m.m*), is soft and slimy. Between the two is very loose connective-tissue, the *submucosa*, which, being easily torn, allows of

the ready separation of the muscular and mucous layers.

In the stomach the mucous membrane is raised into

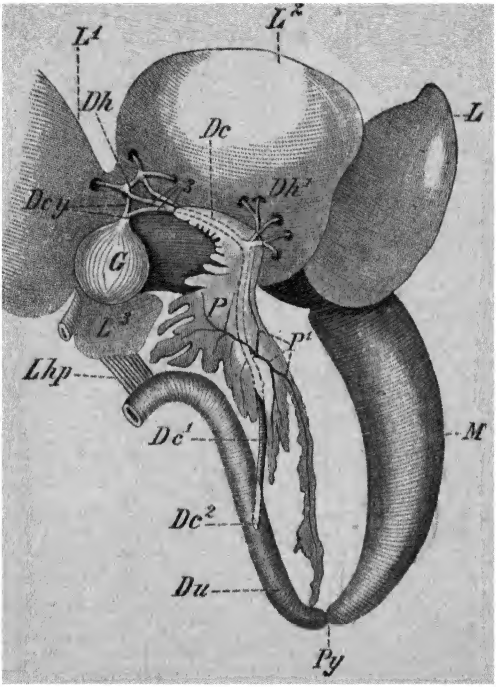

FIG 21.—Stomach and duodenum of *Rana esculenta*, with liver and pancreas ($\times$ 2½) *Dc Dc*¹ common bile-duct, *Dc*² its opening into the duodenum, *D cy* cystic ducts, *Dh, Dh*¹ hepatic ducts, *Du* duodenum, *G* gall-bladder, *L, L*¹, *L*², *L*³, lobes of liver, turned forwards, *Lhp* duodeno hepatic omentum, a sheet of peritoneum connecting the liver with the duodenum, *M* stomach, *P* pancreas, *P*¹, pancreatic duct, *Py.* pylorus (From Wiedersheim's *Comparative Anatomy*)

longitudinal folds (*r*), in order to allow of distension; in an empty stomach these are well marked, and give the cavity a star-like cross-section (Fig. 45), in one

Now the digestible part of the substance of animals consists mainly of two classes of chemical compounds, called *proteins* and *fats*. The most familiar example of a protein is white of egg: other proteins, of varying composition, are found in muscle, in blood, and in other animal tissues. All are composed of the five chemical elements—carbon, oxygen, hydrogen, nitrogen, and sulphur, the five elements being combined in the following proportions:—

Carbon	from	51·5	to	54·5	per cent.
Hydrogen	,,	6·9	,,	7·3	,,
Oxygen	,,	20·9	,,	23·5	,,
Nitrogen	,,	15·2	,,	17·0	,,
Sulphur	,,	0·3	,,	2·0	,,

Fats differ from proteins in containing no nitrogen or sulphur: they are formed of carbon, oxygen, and hydrogen, the number of atoms of hydrogen being typically more than twice as great as the number of atoms of oxygen.

It will be noticed that two important articles of diet are absent from the above list, namely *sugar* and *starch* —the latter the largest constituent of flour, oatmeal, rice, etc. The vegetable substances, such as corn and grass, used as food by animals, contain these bodies in varying proportions in addition to vegetable proteins, and there is no doubt that the frog must eat a small quantity of such vegetable food, if only in the stomachs of the herbivorous animals upon which it preys. Now starch and sugar belong to a group of compounds called *carbohydrates*, composed of carbon, oxygen, and hydrogen, but differing from fats in that the number of atoms of hydrogen is always exactly double that of the atoms of oxygen, as in water. Lastly, the food always contains a certain quantity of saline or mineral matters, as well as water.

Diffusible and Non-diffusible Foods.—These four classes of food materials—proteins, fats, carbohydrates, and minerals—may be arranged in two groups according to a certain physical peculiarity. If a solution of common salt is placed in a vessel with a bottom made of bladder, called a *dialyser*, which is floated in a larger vessel of pure water, it is found that, after a certain lapse of time, the water in the outer vessel has become salt. The sodium chloride has, in fact, passed by *diffusion or osmosis* through the bladder. The same thing will happen if a solution of sugar is placed in the inner vessel: salt and sugar are both *diffusible* substances, capable of passing through an animal membrane.

On the other hand, if the inner vessel contains white of egg, or oil, or starch well boiled in water, no diffusion takes place. Hence proteins, fats, and starch are *non-diffusible* foods, and are thus sharply distinguished from salt and sugar, which are diffusible.

The mucous membrane of the stomach and intestine are animal membranes having the same physical properties as bladder. We may consequently infer that any salt or sugar contained in the enteric canal will diffuse through the mucous membrane and make its way, as we shall see more particularly hereafter, into the blood, thus serving to nourish the whole body. Proteins, fats, and starch, on the other hand, will be incapable of diffusing, and will, therefore, unless some change happens to them, be absolutely useless as nutriment. For, since the enteric canal communicates with the outer world at both ends, the food, paradoxical as it may sound, is practically outside the body as long as it remains in the canal: it is only when it is absorbed into the blood or lymph that it is actually, in the strict sense, taken into the body. Thus if proteins, fats, and starch are to be of any use to the frog, they must, in some way, be rendered capable

of being absorbed, in which process the living tissues appear to exercise some degree of selection.

Action of Digestive Juices.—This is exactly what is done by the digestive juices. If white of egg or any other protein is mixed with gastric juice and kept at a suitable temperature, it is converted into a form of protein called *peptone*, which is capable of diffusing through an animal membrane. The change is effected by means of a substance called *pepsin*, contained in the gastric juice in which there is also a certain proportion of hydrochloric acid. To this the acid reaction of the gastric juice already alluded to (p. 71) is due.

By means of the gastric juice the bodies of the animals swallowed by the frog have their proteins largely converted into peptones, which, being diffusible, pass through the mucous membrane as readily as sugar or salt. Hence the great diminution in the bulk of the food during its sojourn in the stomach: a large proportion of it is absorbed there and then, and only a comparatively small quantity is passed through the pyloric valve into the intestine, where it becomes alkaline, owing to the action of the fluid which enters the duodenum through the bile-duct, and which, as we have seen (p 73), consists of bile and pancreatic juice.

Pancreatic juice has a similar effect on proteins, the change being effected by a substance called *trypsin*, which, however, acts in an alkaline solution. It also has the property of converting starch into sugar, and of splitting up fats into fatty acids and glycerine, both of which are diffusible. The substances by which these changes are effected are called by the general name of *ferments* pepsin and trypsin are protein-converting ferments, and the pancreatic juice also contains a ferment which converts starch into sugar, and a fat-splitting ferment.

The exact mode of absorption of the fats is not thoroughly understood. It is usually supposed that only a small proportion of them are decomposed into fatty acids and glycerine, and that the greater part is merely broken up into particles so small that they can be taken up by the epithelial cells of the intestine. This *emulsification* of fat is effected by the combined action of the pancreatic juice and bile, the fats being reduced to the condition in which they exist in milk and in the emulsions of cod-liver oil so much used in place of the natural form of that medicine.

Thus during the passage of the food through the intestine the remainder of the proteins, the whole of the fats, and any starch which may be present, are rendered capable of being absorbed: they pass through the mucous membrane into the blood, and by the time the rectum is reached all the nutriment is extracted from the food, and there remains only a small quantity of indigestible matter which is passed out in the form of fæces.

In man and other mammals the process of digestion begins in the mouth-cavity. The food is divided into fine particles by the teeth and mixes with a secretion called saliva, which is produced in certain glands (see Part II, Chapter XI) and poured into the mouth-cavity by certain ducts. The saliva is, like the pancreatic juice, alkaline in reaction, and contains a ferment called *ptyalin*, which is capable of converting starch into sugar. There are no salivary glands in frogs, and the teeth also are not for the purpose of masticating the food, but for preventing the prey from slipping out of the mouth.

Most of our knowledge of the processes of digestion is derived from experiments on man and other higher animals. In the course of these it has been established that the mucous membrane of the small intestine also fulfils important functions in the process of digestion When pancreatic juice is first formed, and indeed before it reaches the small intestine, it is unable to act upon proteins. This is because trypsin is only made active and able to do its work when it meets a peculiar substance called *entero-kinase* formed by

the wall of the small intestine Besides this, certain other ferments are also formed by the tubular glands of the intestine in a small amount of the intestinal juice. One of these changes the malt-sugar formed from starchy food and another changes cane-sugar partly into grape-sugar and partly into another sugar like it, called fruit-sugar. Yet another ferment, called *erepsin*, changes peptones into still more soluble substances, called *amino-acids*. The chief function of the mucous membrane of the small intestine, however, is to absorb the digested food. This is carried out by the villi (Fig 23). The epithelial cells covering the villi have the power of taking up, from the fluid in the cavity of the intestine, peptones, and amino-acids formed from them, sugar, salts, and water, as also finely divided fat. They have also the power of passing these substances on to the blood-vessels and lymphatics, although some of these substances become more or less altered during absorption, *e g.*, peptones which are changed into amino-acids, sugar, most of the salts, and a great deal of water pass into the blood-capillaries in the substance of the villi, and are carried by the portal vein to the liver On the other hand, the dissolved fat taken up by the epithelial cells passes into the lacteals and is carried away along the lymphatics, and ultimately reaches into the blood of certain veins into which the lymphatics finally open.

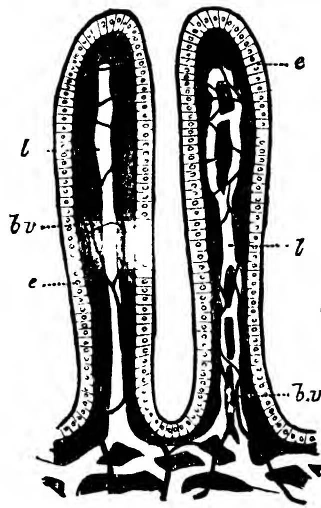

FIG. 23 —Two villi from the intestine of a mammal, highly magnified
e layer of epithelial cells, *b v* blood-vessels; *l* lacteals (From Foster and Shore's *Physiology*)

Peristaltic Movements.—The passage of the food through the enteric canal is effected by the contraction of its muscular layer, which is really double, and which is composed of *muscular fibres* (*see* p. 117, and Figs. 44

and 45). In the inner layer these fibres have a transverse direction, encircling the tube, and by their contraction narrowing it ; the outer layer consists of longitudinal fibres, which by their contraction shorten it. By the alternate contraction and relaxation of the two layers are produced a series of *peristaltic movements*, not unlike those by which an earthworm makes its way over the ground: they can be seen in a freshly-killed frog, and still better in a rabbit or rat.

Summary of Chapter.—The body is constantly undergoing waste, and in consequence needs continual repair. The waste matters chiefly take the form of carbon dioxide, water, and urea. Repair is effected partly by breathing (*see* Chapter IX), partly by feeding. Food, consisting of proteins, fats, carbohydrates, inorganic substances, as well as water, is taken into the enteric canal, where by the action of the three digestive juices—gastric juice, pancreatic juice, and bile—it is converted partly into a solution (peptones, sugar, fatty acids, glycerine), partly into an emulsion (fats). As it is driven along the canal, from stomach to rectum, by the action of the muscular coat, the dissolved or emulsified substances gradually disappear from the canal, and are absorbed into the system. Finally, the indigestible constituents are expelled as fæces.

Our next task must be to learn something of the process of absorption, and of the means by which the digested food is conveyed to the various parts of the body, so as to supply them with the means of repairing the waste they are constantly undergoing. For this purpose we must now study what is called the *vascular system*, *i.e.*, the heart, the blood-vessels, and the various cavities containing lymph.

PRACTICAL DIRECTIONS

The Digestive Organs.—Pin down under water, with the ventral side uppermost, as before, the specimen already dissected, or another in which the body-cavity has been opened in the same way. Note the positions of the *post-caval vein* (Fig. 5, *pt. cv*), the *hepatic portal vein* (Fig. 4, *hp. pt*), the *aorta* (Fig 5, *d ao*), and the *splanchnic* or *cœliaco-mesenteric artery* (Figs. 4 and 5, *cœl mes*). Then, taking care not to injure the aorta, remove the greater part of the digestive organs, including the liver, by cutting through the gullet and rectum and severing the mesentery, cutting through the postcaval also where it enters the liver (The cloaca will be examined at a later stage.) Pin the organs in the dissecting-dish as nearly as possible in their natural position. Turn the lobes of the liver forwards (*i e.*, towards the head), and after making out the relations of the parts already examined *in situ* (pp. 20–23), note—

The *common bile-duct*, formed by the union of the *hepatic* and *cystic ducts*, and the point at which it enters the duodenum (Fig. 21). Make a small slit in the duodenum just opposite its entrance and gently squeeze the gall-bladder between your finger and thumb, so as to force a drop of bile into the intestine (The *pancreatic duct* and its communication with the bile-duct cannot easily be made out by dissection) Sketch the whole dissection

Now remove the liver, unravel the intestine by tearing through the mesentery, and lay open the enteric canal by inserting one blade of the scissors into the gullet, and cutting through the whole tube in a longitudinal direction. Test the contents of the stomach and intestine with litmus paper—(for this experiment a freshly-killed frog is of course necessary)—and then pin out your dissection with the inner surface upwards, wash it under the tap, and examine under water with a magnifying glass. Make out—

1. The *cardia*, *pylorus*, and *pyloric valve*.

2. The *mucous membrane*, and its different appearances in the stomach, small intestine, and large intestine.

3. The *muscular layer*, covered externally by the *peritoneum*.

Make a simple *dialyser* (p. 76) by tying a piece of wet

bladder firmly over one end of a wide glass tube about six inches long. Into this put a solution of sugar or salt, and immerse the tube up to the level of the solution in a rather larger vessel of distilled water, and leave it for a short time: taste the water in the outer vessel. Then place some white of egg in the dialyser, and test for albumen by heating some of the water in the outer vessel over a flame: if albumen is present it will become coagulated and form a cloud in the water.

CHAPTER VI

THE FROG (*continued*): THE VASCULAR SYSTEM—THE CIRCULATION OF THE BLOOD

In our preliminary examination of the frog (Chapter II) we learned one or two facts about the vascular system. We found that there is a heart within a pericardium, two sets of vessels, arteries and veins, containing red blood, and a set of irregular cavities or sinuses, containing lymph. We must now try to get some more accurate and detailed information on these matters.

General Characteristics of Blood and Lymph.—It will be convenient to begin by studying certain easily verified characteristics of the blood. Frog's blood may be used, or, as it is as well to have a considerable quantity, that of some larger, freshly-killed, red-blooded animal, such as a rat or rabbit.

When first drawn from the heart or vessels the blood will be seen to be a fluid, nearly as mobile as water or milk; it "finds its level," like any other liquid, and can be readily poured from one vessel to another. In a few minutes, however, it undergoes a change; it ceases to be fluid, and *coagulates*, or "sets" into a jelly, which, if turned out of the vessel, retains the shape of the latter. Before long a further change takes place; the jelly

begins to shrink, drops of yellowish fluid appear on its surface and gradually run together into larger and larger drops. The jelly contracts still further, and finally draws itself away from the walls of the vessel and floats in the accumulated fluid, still retaining the form of the vessel, but being greatly reduced in size. The process of coagulation of the blood is now complete; the red, jelly-like substance is called the *clot*, the yellowish fluid the *serum*.

When first drawn from most veins the blood is deep purple in colour, and the clot retains for a time the same hue. But before long all parts of it which are fully exposed to the air take on a bright scarlet colour. We may therefore distinguish between red, or *aërated*, and purple, or *non-aërated* blood.

Lymph also coagulates on standing, producing a colourless clot. It is practically blood *minus* its peculiar red colouring matter, the properties of which, as well as the real nature of coagulation, will be discussed in the next chapter.

The Heart: external characters.—Some of the divisions of the heart have already been noticed (p. 20). The *ventricle* (Figs. 4, 5, 8, 24, 25, and 26, *v*, *vt*) is a conical body of a pinkish colour, having its bluntly-pointed apex directed backwards. To its broad base is attached the dark-coloured, thin-walled *auricular division*, actually consisting of two chambers, the *right* and *left auricles* (*r. au*, *l. au*), but appearing single in the entire heart. Passing obliquely across the auricle is a cylindrical structure, the *truncus arteriosus* (*c. art*); it starts from the right side of the base of the ventricle, and passes forwards and to the left, finally dividing near the anterior boundary of the auricles into two branches, which extend respectively right and left.

By lifting up the ventricle, or turning it to one side

(Figs. 5 and 25), there is seen in the dorsal part of the pericardial cavity a thin-walled chamber (Fig. 25, *s. v*) of a dark colour, connected with the right side of the auricular division. This is the *sinus venosus.*

The Arteries.—The two branches of the truncus arteriosus just referred to soon branch again. Each divides into three vessels, often spoken of as *arterial arches,* called respectively the *carotid trunk* (Fig. 24, *car. tr*), the *systemic trunk* (*syst. tr*), and the *pulmo-cutaneous trunk* (*pul. cu. tr*). All these conform to the definition of an artery given on p. 27, *i.e.*, they are stout, elastic vessels, containing little blood after death, and not collapsing when empty.

The carotid trunk divides immediately into two, a *lingual artery* (*lg*), which can be traced to the tongue, and a *carotid artery* (*car*), which branches repeatedly, its ultimate ramifications going to various parts of the head. At the origin of the carotid is a little rounded mass with a sponge-like interior, the *carotid labyrinth* (*car. gl*).

The systemic or aortic trunk extends outwards, in contact with the gullet, then sweeps upwards, backwards, and inwards—*i.e.*, towards the middle line—and finally joins with its fellow of the opposite side to form a single median vessel, the *dorsal aorta* (Figs. 5, 6, and 24, *d. ao*), which passes backwards just beneath the vertebral column and between the kidneys.

As it sweeps round the gullet, the systemic trunk gives off a *vertebral artery* (Fig. 24, *vert*) to the vertebral column and part of the head, a *subclavian artery* (*scl*), passing into the fore-limb as the *brachial,* and an *œsophageal artery* (*œs*) to the gullet.

From the point of union of the two aortic trunks springs a single *splanchnic* or *cœliaco-mesenteric artery* (*cœl. mes*); it divides into several branches, which are

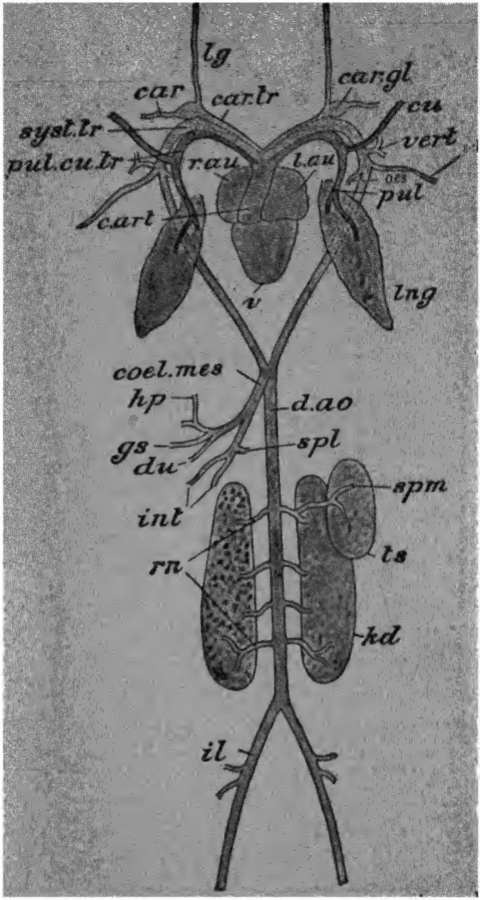

FIG. 24.—The arterial system of the Frog, with the heart, lungs, kidneys, and left spermary, supposed to be removed from the body and viewed from the ventral aspect. (× 2.)

car. carotid artery; *car gl* carotid labyrinth; *c. art.* truncus arteriosus; *car. tr* carotid trunk; *cœl mes.* splanchnic or cœliaco-mesenteric artery; *cu* cutaneous artery; *d. ao.* dorsal aorta; *du.* duodenal artery; *gs.* gastric artery; *hp.* hepatic artery; *il.* iliac artery; *int.* intestinal arteries; *kd* kidney; *l au.* left auricle; *lg.* lingual artery; *lng* lung; *œs* œsophageal artery; *pul* pulmonary artery; *pul cu tr* pulmo-cutaneous trunk; *r. au* right auricle; *rn.* renal arteries; *scl* subclavian artery; *spl* splenic artery; *syst. tr.* systemic trunk; *spm* spermatic artery; *ts* spermary; *v* ventricle; *vert.* vertebral artery. (From Parker and Haswell's *Zoology*.)

traceable to the liver (*hp*), stomach (*gs*), duodenum (*du*), spleen (*spl*), and ileum (*int*).

The dorsal aorta gives off on either side four *renal arteries* (*rn*) to the kidneys, and *spermatic arteries* (*spm*) in the male, or *ovarian* in the female, to the reproductive organs, and at the posterior end of the abdominal cavity divides into the right and left *iliac arteries* (*il*). Each iliac gives off a small *hypogastric* to the bladder, and then passes into the hind-limb as a *sciatic*. Just before the point of bifurcation of the aorta, a small *posterior mesenteric artery* is given off to the rectum.

The pulmo-cutaneous trunk divides into two main branches, the *pulmonary artery* (*pul*) which goes to the lung, and the *cutaneous artery* (*cu*) which forms an extensive system of branches over the skin.

With proper care all these arteries can be traced into the various organs to which they are distributed, when they will be found to branch repeatedly, sending ramifications to all parts. The iliac artery, for instance, may be followed along the whole length of the leg, giving off branches to all the muscles, to the skin, and to the digits, with their intervening web.

The Veins.—Since every part of the body has its vein as well as its artery, there is a rough correspondence between the two kinds of blood-vessel. The arrangement of the principal trunks is, however, very different in the two cases.

On either side of the base of the heart is a large vein called the *precaval* or *vena cava anterior* (Figs. 4 and 25, *pr. cv*): by turning the ventricle aside, the two precaval veins can be seen to join the anterior end of the sinus venosus (*s. v*). Each precaval is formed by the confluence of several veins, of which the most important are the *external jugular* (*ext. ju*) from the lower jaw and tongue, the *internal jugular* (*int. ju*) from the brain, eye,

etc., and the *subclavian* (*scl*), formed by the union of the *brachial*(*br*), from the fore-limb, and the *musculo-cutaneous* (*ms. cu*), already noticed, from the superficial parts of the head and part of the skin and muscles of the abdomen.

With the posterior end of the sinus venosus is connected a single large vein, the *postcaval* or *vena cava posterior* (*pt. cv*), a wide vessel lying between the kidneys and extending forwards to the liver (Fig. 5). It runs parallel with and beneath, *i.e.*, ventral to, the dorsal aorta (Fig. 5), from which it is at once distinguished by its greater diameter. Posteriorly it is formed by the confluence of five or six *renal veins* (Fig. 25, *rn*) from each kidney, and it also receives, in the male, *spermatic veins* (*spm*) from the spermaries, and in the female, *ovarian veins* from the ovaries. Anteriorly it perforates the liver; receiving two *hepatic veins* from that organ, and finally enters the sinus venosus.

We have now to consider a striking want of correspondence between the arterial and venous systems of the frog. As you will remember, the dorsal aorta, after giving off the renal arteries, passes backwards and divides into the two iliac arteries for the legs. You might naturally expect a somewhat similar arrangement with the veins, especially if you have studied human physiology and learnt how the posterior (or inferior) vena cava of man is formed by the confluence of the veins from the legs, and receives higher up those from the kidneys. In the frog, as we have just seen, the postcaval does not reach to the hinder boundary of the kidneys, and the renal veins are the only vessels entering it posteriorly.

In the frog, as a matter of fact, the connections of the veins of the legs are very peculiar. You remember the abdominal vein seen in our preliminary dissection

venosus, and discharges, with its fellow of the opposite side, into the left auricle.

Character of the Blood in the Arteries and Veins.—There are certain differences between the arteries and veins in respect of the blood they contain. As a rule, the veins contain purple or non-aërated blood, the arteries more or less thoroughly aërated or scarlet blood. But there are certain exceptions. As we shall see in a later chapter, the blood is aërated in the lungs and skin; hence the blood returned from those organs by the pulmonary and musculo-cutaneous veins is aërated. On the other hand, the blood in the pulmo-cutaneous artery is non-aërated.

Flow of Blood.—We must now try to understand the function of this complicated blood-system, and the reason why every part of the body has two vessels, an artery and a vein. That there is some kind of movement of the blood has been hinted in the foregoing description, in which arteries have been described as branching out to various parts, veins as formed by the confluence of smaller veins from various parts.

If an artery were cut in a living frog, the blood would be found to flow out in a series of jerks corresponding with the beats of the heart. Moreover, the blood would flow from the side of the cut nearest to the heart, and the flow might be stopped by tying or compressing the artery on that side, *i.e.*, between the heart and the cut. Evidently, then, the blood in the living animal flows from the heart along the arteries to the various parts of the body, and is propelled by the pulsation of the heart.

If a vein were cut the result would be very different. The blood would flow in a comparatively slow stream and without jerks; it would flow, moreover, from the side of the cut furthest from the heart, so that, in order to stop the bleeding, the vein must be tied or com-

pressed on the far side of the cut. The blood in the veins flows, therefore, towards the heart in an even stream, unaffected by the heart's pulsations.

Thus the blood is driven by the heart to the various parts of the body through the *efferent* arteries, and is returned from the various parts of the body to the heart by the *afferent* veins. Two questions thus naturally arise: how is it that the blood takes this direction and not the other, and how does it make its way from the artery of a given organ into the vein?

Internal Structure of the Heart.—To answer the first question—why the blood leaves the heart by the arteries and returns to it by the veins, and not *vice versâ*—we must examine the heart itself in some detail.

The ventricle is a hollow structure with thick spongy walls and a small cavity (Fig. 26, *v*), and there are two perfectly distinct auricles, the right (*au'*), considerably larger than the left (*au"*), separated from one another by a vertical partition (*a. s.*).

You have already seen that the truncus arteriosus arises from the right side—the frog's right, not yours—of the base of the ventricle. A little to the left of this point there is an aperture through which a bristle can be passed from the ventricle into either of the auricles. Both auricles, then, communicate with the ventricle, by a single *auriculo-ventricular aperture*. This is guarded by two little membranous flaps (*va'*), which spring, one from the dorsal, one from the ventral edge of the aperture, and hang down into the ventricle, to the walls of which they are attached by little tendinous cords, represented in the figure by white streaks. Thus the flaps have the character of folding doors or *valves* opening only one way; they readily flap backwards, *i.e.*, into the ventricle, but are prevented from flapping forwards, or into the auricles, by the tendinous cords attached to

to become dorsal. The cavum aorticum leads more directly to the ventral portion of the synangium, from which the right and left carotid (*ca*) and systemic (*ao*) trunks arise. The pulmo-cutaneous trunks (*p. cu*) spring from the conus by an aperture (*p. cu'*) situated just posteriorly to a valve, and itself guarded by a small valve.

In the dorsal wall of the right auricle is a large transverse aperture, by which the sinus venosus communicates with the auricle; it is therefore called the *sinu-auricular aperture;* its two edges are produced into flaps, the *sinu-auricular valves* (*va''*), which allow free passage from the sinus to the right auricle, but prevent any flow in the opposite direction. In the dorsal wall of the left auricle, situated more anteriorly, is the circular opening of the pulmonary veins (*p. v'*).

Valves of the Veins.—In addition to the valves of the heart, many of the veins contain small watch-pocket valves, all arranged with their concavities directed towards the heart, so as to allow of a free passage in that direction. Any attempt to flow in the opposite direction, *i.e.*, from the larger to the smaller veins, will result in filling the valves, bringing their edges into contact with the opposite wall of the vein and thus effectually blocking the passage.

Circulation of the Blood.—We see then that an investigation of the structure of the heart shows that fluid can traverse it in one direction only, viz., from the sinus to the right auricle, from the auricles to the ventricle, from the ventricle to the conus, and from the conus to the bulbus aortæ, and so to the arteries. The valves in the veins are so arranged as to allow the blood in these vessels to flow only towards the heart. The experiment of cutting the vessels shows that the blood in the arteries does actually flow from the heart, that in the

veins towards the heart. We thus demonstrate that there is not merely a movement but a true *circulation* of the blood, the current starting from the heart, passing by the arteries to all parts of the body, and being returned to the heart by the veins.

Action of the Heart.—The circulation of the blood is effected by the pulsation of the heart. This organ is made of muscle; each of its cavities is to be considered as a bag, the walls of which are formed of muscular fibres crossing one another in various directions and encircling the cavity. We have seen that when an ordinary spindle-shaped muscle contracts, its two ends are brought nearer together. When a hollow muscular bag contracts the effect will be to squeeze the walls together and so diminish the cavity. Hence when any chamber of the heart contracts it must expel a part or the whole of its contained blood. The contraction of the chambers of the heart takes place in regular order: first the sinus, then the two auricles together, then the ventricle, and lastly the conus. The contraction (*systole*) in each case is visible as a sort of throb and is followed by a period of rest, during which the chamber regains its former dimensions (*diastole*).

The course of the blood through the heart will now be clear. When the sinus (Fig. 27, *s. v*) contracts, the contained blood, which, coming by the precavals and postcaval, is non-aërated, is acted upon in all directions and might therefore be forced either into the three great veins (*pr. cv. v*, *pt. cv. v*) or into the right auricle (*r. au*). But the veins are full of blood steadily flowing towards the heart, and any regurgitation is further prevented by their valves: the right auricle, on the other hand, has finished its contraction and is now relaxing; it is therefore empty. Thus, on the principle of least resistance, the contraction of the sinus fills the right auricle with

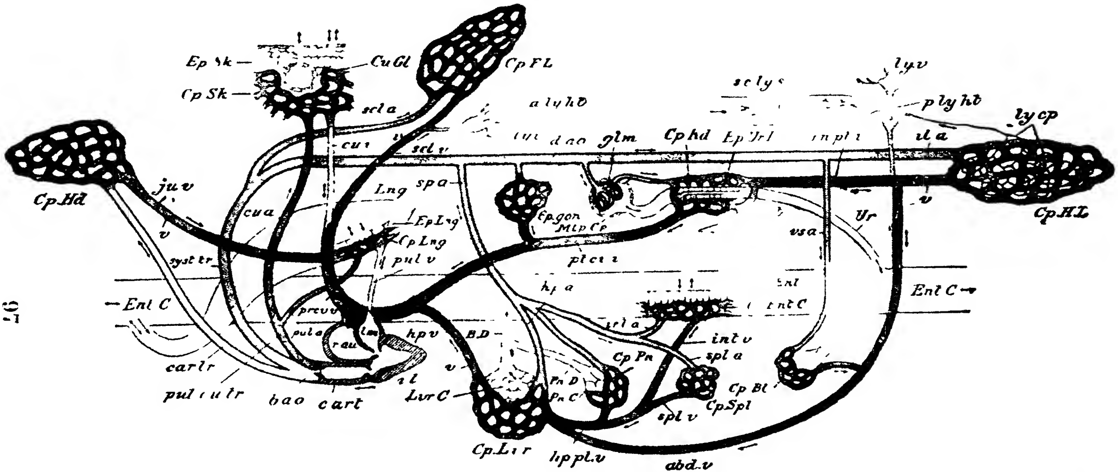

FIG 27 —Diagram showing the course of the blood and lymph in the Frog, and indicating the losses and gains to the blood during its progress (For an account of these processes see Chap. IX, where the figure will be again referred to) The arteries have thick, the veins and capillaries thin, outlines, the smaller lymphatic vessels are black, the larger are dotted The degree of aëration of the blood is indicated by the depth of shade, from white (fully aërated) to dark grey (non-aërated) The enteric canal (*Ent C*) is represented as a straight tube having connected with it the lung (*Lng*), bile-duct (*B D*), urinary bladder (*U Bl*), and ureter (*Ur*) The various epithelia and glands are represented diagrammatically by groups of cells, and the kidney is indicated by a single urinary tubule with its Malpighian capsule. The arrows indicate the direction of flow in the vessels and the course taken by the various substances taken into or given out from the blood, glands, etc

abd v abdominal vein; ***a ly ht.*** anterior lymph-heart, ***b ao*** bulbus aortæ, *B D* bile duct, *c art* conus arteriosus, ***car. tr*** carotid trunk, ***cœl*** cœlome, *Cp Bl* capillaries of urinary bladder; *Cp Ent C.* of enteric canal, *Cp F L* of fore-limb, *Cp gon* of ovary

or spermary, *Cp. Hd.* of head; *Cp H. L.* of hind-limb; *Cp. Kd.* of kidney; *Cp. Lng.* of lung; *Cp. Lvr.* of liver; *Cp. Pn.* of pancreas; *Cp Sk.* of skin; *Cp. Spl* of spleen; *cu. a* cutaneous artery; *cu. v* cutaneous vein; *Cu Gl.* cutaneous gland; *d. ao.* dorsal aorta, *Ent C* enteric canal; *Ep. Ent.* epithelium or enteric canal; *Ep Lng* of lung, *Ep Sk* of skin; *Ep Ur. T.* of urinary tubule; *glm* glomerulus, *il a* iliac artery, *int a* artery to stomach and intestine; *int. v* vein from stomach and intestine; *ju v* jugular vein; *hp a* hepatic artery (to liver), *hp pt v* hepatic portal vein; *hp v.* hepatic vein; *l au* left auricle; *Lng* lung, *Lvr C* liver-cells, *ly cp.* lymph capillaries; *ly. v* lymphatic vessels; *Mlp Cp* Malpighian capsule; *nst* nephrostome; *p. ly. ht* posterior lymph-heart, *Pn C.* cells of pancreas; *Pn D.* pancreatic duct; *pr cv v* precaval vein; *pt. cv. v.* postcaval vein; *pul. a* pulmonary artery, *pul cu. tr.* pulmo-cutaneous trunk; *pul v* pulmonary vein, *r. au* right auricle; *rn pt. v* renal portal vein; *scl. a* subclavian artery, *s. c. ly. s.* sub-cutaneous lymph-sinus; *scl v* subclavian vein; *sp a* splanchnic artery; *spl a* splenic artery, *spl. v* splenic vein, *s v.* sinus venosus; *syst tr* systemic trunk; *U Bl* urinary bladder; *Ur* ureter; *v* valve in vein; *vs. a* vesical artery (to bladder); *vs v* vesical vein, *vl* ventricle.

blood from the great veins, and the sinus itself is refilled from the same source as soon as it begins to relax.

Immediately after the sinus has ceased to contract the two auricles contract together: the right, as we have seen, has just been filled from the sinus, the left (*l. au*) is full of aërated blood brought to it by the pulmonary vein (*pul. v*). The presence of the sinu-auricular valves prevents the blood in the right auricle from being forced back into the sinus: that in the left auricle is prevented from being forced back into the pulmonary veins by the steady onward flow in the latter. On the other hand the ventricle is beginning to relax and is empty. Consequently the auriculo-ventricular valves are forced back into the ventricle (*vl*) and the blood from both auricles flows into and fills that chamber, the right half of which becomes filled with non-aërated, the left with aërated blood, the two taking an appreciable time to mingle, owing to the spongy character of the ventricular wall.

The instant it is thus filled, the contraction of the ventricle begins. As it does so the blood, getting behind the auriculo-ventricular valves, forces them together, and thus prevents any backward flow into the auricle. At the same time the semilunar valves at the entrance of the conus (*c. art*) are pushed aside and the

blood flows into that chamber. Since the conus opens from the right side of the ventricle, the blood first entering it will be non-aërated; there will then follow a certain amount of mixed blood; and finally, as the ventricle reaches the limit of its contraction, the aërated blood from its left side will be forced into the conus (compare Fig. 26).

Two alternative courses are now open to the blood: it can pass either directly from the conus into the pulmo-cutaneous trunk (*pul. cu. tr*), or make its way into the bulbus aortæ (*b. ao*). As a matter of fact the non-aërated blood first entering the conus is diverted by the longitudinal valve almost exclusively into the cavum pulmo-cutaneum, and passes into the pulmo-cutaneous trunks, owing to the circumstance that there is little resistance in the limited blood-system of the lungs, while that in the systemic and carotid trunks is very great. Hence the blood first received into the conus from the ventricle, which, as we have seen, is non-aërated, goes immediately to the lungs and skin to be aërated.

As these are filled, their resistance increases, and the mixed and later the aërated blood flows through the cavum aorticum into the bulbus aortæ. The conus also by its contraction brings the free ventral edge of the longitudinal valve into contact with its ventral wall, and the blood passing on the right of the longitudinal valve flaps it over the pulmo-cutaneous aperture and prevents any further blood entering it. In the bulbus, again, the question of pressure comes in. It is easier for the blood to make its way into the wide systemic trunks (*syst. tr*) uniting immediately into the long dorsal aorta (*d. ao*) than into the comparatively narrow carotid trunks (*car. tr*), obstructed by the carotid labyrinths. Hence, the non-aërated blood having been mostly driven into the pulmo-

cutaneous trunk, the mixed blood, from the middle part of the ventricle, goes into the systemic trunk, and thence to the various arteries supplying the limbs (*scl. a, il. a*) and the viscera (*sp. a*, etc.). Finally, when the pressure is sufficiently raised in the systemic trunks, the remaining blood, which, coming from the left side of the heart, is aërated, is pumped into the carotid trunks (*car. tr*), and thence to the head.

Thus, owing to the arrangement of the valves, and to the varying pressures in different parts of the vascular system, the non-aerated blood returned from the various parts of the body to the heart is mostly sent to the lungs and skin to be aërated. Mixed blood is sent to the trunk, limbs, and viscera, while for the head with its contained brain—the directing and controlling organ of the whole animal—a special supply of pure, aërated blood is reserved.

We see then that the course of the circulation may be proved, as a simple matter of induction, from the structure of the heart and its valves, the direct observation of its beat, and the manner in which the flow from cut vessels takes place. It was by observation and experiments of this kind that the circulation of the blood in the higher animals was demonstrated by William Harvey in the seventeenth century. But the final and most conclusive proof of the circulation—from directly observing the flow—became possible only after the invention of the microscope. This instrument, by furnishing a sufficiently high magnifying power, allows us to see for ourselves the actual movement of the blood in an animal or organ of sufficient transparency; and at the same time clears up the question, previously insolvable, of how the blood, having reached a given part or organ by the arteries, finds its way into the veins to begin its return journey.

The Circulation in the Frog's Web.—There are three parts in the frog transparent enough to allow of the blood-flow being seen in them—the web of the foot, the tongue, and the mesentery. Of these the web is the most convenient, and can be examined under the microscope without any injury to the animal.

The Capillaries.—If you have the makings of a naturalist, you will acknowledge the sight to be one of the most wonderful you ever saw. In the thickness of the web is an irregular network of minute blood-vessels, called *capillaries* (Fig. 28), and through them the blood is seen to flow with great rapidity, its course being made especially evident by the minute particles or *corpuscles* it contains, the structure of which we shall study later on (Fig. 31). You will also notice much larger vessels, the smallest arteries and veins. The arteries (*a*) are distinguished by the fact that the blood in them flows in the direction from the leg towards the margin of the web, while in the veins (*v*) it takes the opposite direction. You must remember, however, that under the microscope everything is reversed; right appears left and left right, and a current actually flowing towards the observer appears to go in the opposite direction.

By careful examination you will see that both arteries and veins are in connection, by minute branches, with the capillary network, and will be able to trace the blood from an artery, through the capillaries, into a vein.

The same thing can be seen in other transparent organs; and by injecting the vascular system with a fluid injection-mass, such as gelatine suitably coloured, it can be proved that all parts of the body are permeated with a capillary network into which the blood is passed by the arteries, and from which it is received into the veins.

Thus by means of the microscope we are able to take the final step in demonstrating the circulation. The fact that the blood can flow in one direction only is

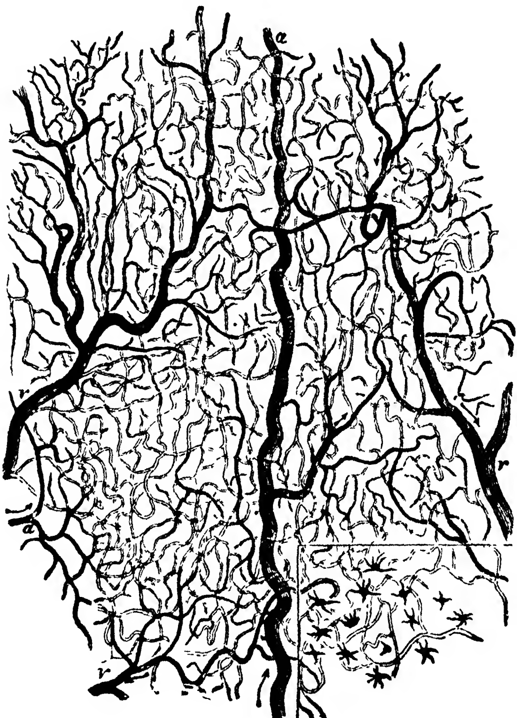

FIG 28 —Blood-vessels of the web of a Frog's foot seen under a low magnifying power. *a*. small arteries, *v* small veins. The minute tubes joining the arteries to the veins are the capillaries The arrows show the direction of the circulation. In the small portion marked off, the pigment cells of the skin, which occur throughout the web, are also represented. (From Huxley's *Physiology*.)

proved by the disposition of the valves of the heart and of the veins, but the passage of the blood from the smallest arteries to the smallest vein by a connecting

system of minute tubes or capillaries can be proved only by the employment of considerable magnifying powers. We see that the vascular system of the frog is a closed system of vessels: the blood is everywhere confined within definite tubes through which it flows in a definite direction, never escaping, as in some of the lower animals, into large irregular spaces among the tissues.

The Lymphatic System.—Included in the vascular system are certain cavities and vessels containing lymph, and together constituting the *lymphatic system*. We have already noticed the subcutaneous lymph sinuses (p. 18, and Fig. 27, *s.c.ly.s*) and the sub-vertebral lymph-sinus (p. 26, Fig. 6, *s.v.ly.s*). There are also found in nearly all parts of the body delicate, thin-walled, branching tubes, the *lymphatic vessels* (Fig. 27, *ly. v*). Unlike the blood-vessels, the lymphatics are all of one kind, there being no distinction into anything of the nature of arteries and veins. They arise in *lymph-capillaries* (*ly. cp*), which are, as it were, interwoven with the blood-capillaries, but have no connection with them. By the lymph-capillaries the fluid which has exuded from the blood in its passage through the tissues is taken up and passed into the lymphatic vessels or sinuses, and these in their turn finally communicate with certain transparent muscular organs called *lymph-hearts*. Of these there are two pairs. The anterior lymph-hearts (*a. ly. ht*) lie, one on either side, beneath the supra-scapula and just behind the transverse process of the third vertebra: the posterior pair (*p. ly. ht*) are situated one on each side of the posterior end of the urostyle. These organs pulsate regularly, like miniature hearts, and pump the lymph into the veins, the anterior pair communicating with the subclavian, the posterior with the renal portal vein.

The lymphatics of the enteric canal have an important function to perform in that they absorb the fatty portions of the food (p. 78). The fluid they contain has a milky appearance, owing to the presence of minute suspended fat-globules, and for this reason they receive the name of *lacteals*.

The cœlome is really a great lymph-sinus (Fig. 27, *cœl*). It communicates with the veins of the kidneys through certain microscopic apertures called *nephrostomes* (*nst*).

The **spleen** (p. 23, and Fig. 4, *spl*) has important relations with the blood- and lymph-vessels, and probably acts as a blood-filter, removing old and worn-out red corpuscles and foreign micro-organisms from the blood. The white corpuscles of the blood divide and multiply in numbers in the spleen.

Ductless Glands.—There is a pair of **thyroid** glands. Each is a small rounded or lobulated body, situated ventral to and in close connection with the external jugular vein. The thyroids secrete a substance rich in iodin. Nothing is known of the functions of the thyroid in the frog, but in higher vertebrates, the removal of the gland leads to serious disturbances and proves fatal. So it is inferred that the gland pours some useful secretion directly into the blood-stream. The **thymus** is another such gland. It is a small, oval, reddish-looking body, situated close behind the tympanic membrane, near the angle of the jaw.

PRACTICAL DIRECTIONS

The Vascular System.

a. Let some blood from a frog—or better from the veins of some larger, freshly-killed, warm-blooded animal, such as a rat or a rabbit—flow directly into a white cup or porcelain capsule. Note that it soon *coagulates*, and shortly afterwards separates into *clot* and *serum*. Notice also the difference in colour between the blood freshly drawn from a vein (see p 91), and that soon assumed by exposed portions of the clot.

Injection of the Veins.—The veins are much more difficult to inject than the arteries, but if you wish to make a double injection on the same specimen, colour the injection-mass with vermilion or carmine in the case of the arteries instead of with French blue, using the latter for the veins. The operation is best performed by inserting the nozzle into an incision in the abdominal vein (by directing the nozzle forwards, the portal vein will be injected : by directing it backwards the pelvic and renal portal veins), and also into one of the subclavians. But for a really satisfactory preparation, it is best to inject from the heart through the conus, as directed above, with a weak, warm solution of gelatine (in the proportion of one part of gelatine to two parts of water), coloured with precipitated carmine. In this case the injection-mass, containing only microscopic particles, passes from the arteries through the capillaries into the veins, keeping throughout to the course taken by the blood during life, and therefore unimpeded by the valves of the veins. A syringe must be used, since the medicine dropper will not give sufficient pressure, and the animal should be placed in warm water during the process

II. Now pin down under water and make out the course of the chief *veins* (p. 87, Figs. 4 and 25) —

1. The two *precavals*, and the *external jugular*, *internal jugular*, *subclavian*, and *musculo-cutaneous*

2. The *postcaval*, to see which turn the viscera on one side (Figs 5 and 25). Note the *renal*, *spermatic* or *ovarian*, and *hepatic veins*.

3. The *hepatic portal vein* and its factors.

4. The *abdominal vein* and *pelvic* veins.

5. The veins from the hind-legs can be more easily seen at a later stage, after the alimentary canal is removed, and so their examination is best left until certain of the arteries have been traced (or use the specimen you have dissected previously for this purpose). Remove the skin from the thigh, place the frog on its side, and make out the *femoral*, *pelvic* (already seen), *renal portal*, and *sciatic veins*, as well as a large vein from the muscles of the back.

6. The two *pulmonary veins*.

Make a sketch of the heart and as many of the veins as you have followed out up to this point, inserting the others after removing the alimentary canal (see p. 108).

III. The chief *arteries* may now be followed out (p. 85, Fig. 24) :—

Note the *carotid*, the *systemic*, and the *pulmo-cutaneous* trunk, arising from the truncus arteriosus, and then trace each of these out as follows —

1. The *carotid trunk* gives off a *lingual artery* and is continued into the head as the *carotid artery*, having at its origin the *carotid labyrinth*.

2. The *systemic trunk* unites with its fellow to form the *dorsal aorta*, first giving off *vertebral*, *subclavian*, and *œsophageal arteries*. From the point of union of the two systemic trunks arises the *splanchnic* or *cœliaco-mesenteric artery*. After following this out to its distribution, remove the alimentary canal as directed on p. 81, when the following branches of the dorsal aorta will be more plainly seen —the *renal*, *spermatic* or *ovarian*, and *iliac arteries*.

3. The *pulmo-cutaneous trunk* divides into a *pulmonary artery*, passing along the outer side of the corresponding lung, and a *cutaneous artery*.

Sketch the heart and chief arteries, and then make out and sketch the renal portal system (p. 107), if you have not already done so.

IV [1] Cut out the heart of a frog preserved in formaline, taking great care not to injure it. Fasten it down in a dissecting-dish, with the ventral surface upwards, by sticking very small pins through the arteries and veins—not through the heart itself. Pinch up the ventricle with fine forceps, and with small scissors gradually snip away its ventral wall, noting that it is a hollow structure with thick, spongy walls and a small cavity, which will probably be full of clotted blood. Wash this out and then proceed to open the auricles in a similar way, and to wash out the blood they contain. Observe the *right* and *left auricles*, separated by a partition. Slit open the conus arteriosus, and continue the cut forwards to the origin of the main arteries. Examine with a lens and make out (p. 92, Fig. 26) :—

1. The *auriculo-ventricular aperture* and its *valves*.

2. The *longitudinal valve* and the small *semilunar valves* in the conus arteriosus.

3. The *origins* of *the carotid* and *systemic trunks* from the *bulbus aortæ*, and the small aperture leading into the *pulmo-cutaneous trunks*.

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[1] On account of its small size, the examination of the structure of the frog's heart is somewhat difficult, and the student is advised to dissect first the heart of a larger animal, such as a sheep (Part II, Chap. IX).

4. The *sinu-auricular aperture* and its *valves*.

5. The aperture in the left auricle leading into the pulmonary veins.

Sketch.

Turn over the heart, so that its dorsal surface is upwards, and cut away enough of the dorsal wall of the sinus venosus to show the sinu-auricular aperture from the other side.

V. Get a piece of thin board—*e g.*, the side of a cigar-box—about six inches long by three wide. Towards one end make a round hole about half an inch in diameter, and opposite this, on either side, make a notch, or rather slit, with a penknife. This is called a "frog-board."

Next get as light-coloured a frog as possible. The web may be examined in the living animal without hurting it, or the animal may be first chloroformed as directed on p. 31, but removed from the influence of the anæsthetic as soon as it is insensible, so that there may be no suspicion of the frog feeling any inconvenience from this harmless experiment. Lay the frog on the frog-board with a piece of wet rag wrapped loosely round the body, and take one or two turns around both frog and board with a piece of tape—you must avoid tying it tightly or the circulation will be impeded. Stretch out one leg, and selecting the most transparent web, tie a piece of thick soft silk round each of the two toes by which it is bounded. Adjust the leg so that the web comes just over the hole in the frog-board, and bring the two pieces of silk through the slits, regulating them until the web is evenly stretched out over the hole. Lastly, place the frog-board on the stage of the microscope,[1] with the hole over the aperture in the stage, and either fix it with the clips or rest the opposite end on some support : adjust the mirror so as to illuminate the web from beneath, and examine it with the low power. Note the network of *capillaries* and the *circulation of the blood* through the arteries, capillaries and veins (Fig. 28).

[1] A brief description of the compound microscope will be given at the end of the next chapter (p. 126).

CHAPTER VII

THE FROG (*continued*) : THE MICROSCOPICAL EXAMINATION OF THE SIMPLE TISSUES

BEFORE carrying our inquiries any further into the anatomy and physiology of the frog it will be necessary to devote some consideration to its microscopic structure or *histology*, since there are many matters in connection with the various organs which can be further elucidated only by the examination of the minute structure of the organs as revealed by the microscope (*see* p. 126).

Let us, first of all, examine a drop of the frog's **blood** under the low power of the microscope. It will at once be seen that the blood is not a simple homogeneous fluid, but that it contains a large number of minute solid bodies floating in it. These are called by the general name of *blood-corpuscles :* the fluid part of the blood in which they float is called the *plasma*. At first, owing to currents in the fluid, the corpuscles will be found to move to and fro, but after a time they come to rest. Under the high power you will notice that the corpuscles are of two kinds. The greater number of them are regularly oval in form (Fig. 30, C), and of a yellow colour. If the drop of blood is thick enough in one part for the corpuscles to lie over one another, so that the light passes through two or three layers of them to reach the

eye, they will appear red: they are hence called *red corpuscles*. Frequently they are seen turned on edge (D), and their appearance in this position shows them to be flat, oval discs with a swelling in the centre. They are about $\frac{1}{40}$th of a millimetre (about $\frac{1}{1000}$th inch) in long diameter.

Among the red corpuscles are found, in much smaller numbers, bodies not more than half the long diameter of the red corpuscles in size, quite colourless, distinctly granular—so as to have the appearance of ground glass —and with a slightly irregular outline (Fig. 30, A).

FIG 30.—Blood-corpuscles of the Frog (× 525.)
A, colourless corpuscle, B, the same in process of division, C, red corpuscle, surface view; D, the same, edge view. *nu* nucleus (From Parker's *Biology*)

These are the *colourless corpuscles* or *leucocytes*. They are not flat, like the red corpuscles, but have the form of irregular lumps.

The plasma, like the leucocytes, is quite colourless, so that the colour of the blood is seen to be due entirely to the large number of red corpuscles it contains.

If the drop of blood has been prepared and examined under the high power with sufficient rapidity, a remarkable phenomenon can be made out with regard to the colourless corpuscles. This can be most easily demonstrated by making a series of outline sketches of the same leucocyte at intervals of a minute or two. You will then notice that the sketches all differ from one another: in one there will perhaps be a little projection going off to the right; in the next this will have disappeared and a similar projection will have appeared on the left, and so

on. As a matter of fact, as long as the blood is quite fresh, the leucocytes are in constant movement, sending out and withdrawing little processes of their substance called *pseudopods* or "false feet," by means of which they can crawl slowly along like independent living things. These very peculiar and characteristic movements are called *amœboid movements.* Occasionally a leucocyte may be seen to elongate itself and divide into two (Fig. 30, B): this is a case of what is called *simple fission.* The red corpuscles neither move nor divide.

If a drop of some dye or staining fluid (p. 128) be run in under the cover-glass, the corpuscles will be seen to become rather faint in outline, transparent, and lightly tinted; but the most obvious effect is that in the middle of each is seen a rounded or oval granular body (*nu*) deeply stained by the dye, so as to make a very well-defined coloured area in the interior of the corpuscle. This body is called the *nucleus:* it is present both in the red and the colourless corpuscles.

By adding to a fresh drop of blood, in the same manner, a drop of weak acetic acid, the nucleus again becomes distinct, while the body of the corpuscle is rendered very transparent and almost invisible: indeed it finally disappears altogether. It is thus proved that the corpuscles, both red and colourless, consist of a substance which is known as *protoplasm,* but slightly affected by dyes, and soluble in weak acids; and enclosed in this is a nucleus, stained by dyes, and unaffected by weak acids. Both nucleus and protoplasm consist mainly of proteins (p. 75), together with water and a small proportion of mineral matters.

When distilled water is added to a drop of blood on the slide, the corpuscles are seen to swell up and become partly dissolved: the red colouring matter of the red corpuscles is dissolved out, the plasma becoming tinged

with yellow. Thus the colouring matter is evidently a distinct substance from the protoplasm, and is called *hæmoglobin*. It is characterised, among other things, by a strong attraction for oxygen: in combination with that gas it assumes a bright scarlet colour; when deprived of oxygen, it becomes purple. This affinity for oxygen accounts for the change undergone by the blood when exposed to the air, as described on p. 91.

Coagulated blood, as seen under the microscope, is characterised by the plasma being traversed by extremely delicate threads, forming a sort of network in which the corpuscles are entangled. These threads are formed of a substance called *fibrin*, which is separated from the plasma during coagulation, the remaining or fluid portion of the plasma constituting the *serum*. We may therefore express the coagulation of the blood in a diagrammatic form as follows:—

Fresh Blood.	*Coagulated Blood.*	
Plasma	Serum	
	Fibrin	Clot.
Corpuscles		

Having observed the microscopic characters of a drop of blood, let us examine once more the circulation in the web, this time under the high power (Fig. 31). The red corpuscles (*F*) can be seen streaming through the vessels, those in the capillaries in single file, those in the small arteries and veins, two or more abreast: as they pass through narrow capillaries or round corners, they become bent or squeezed (*G*, *H*). The leucocytes (*I*) travel more slowly and often stick to the sides of the vessels.

Columnar Epithelium.—By carefully teasing out a small piece of the inner surface of the mucous membrane

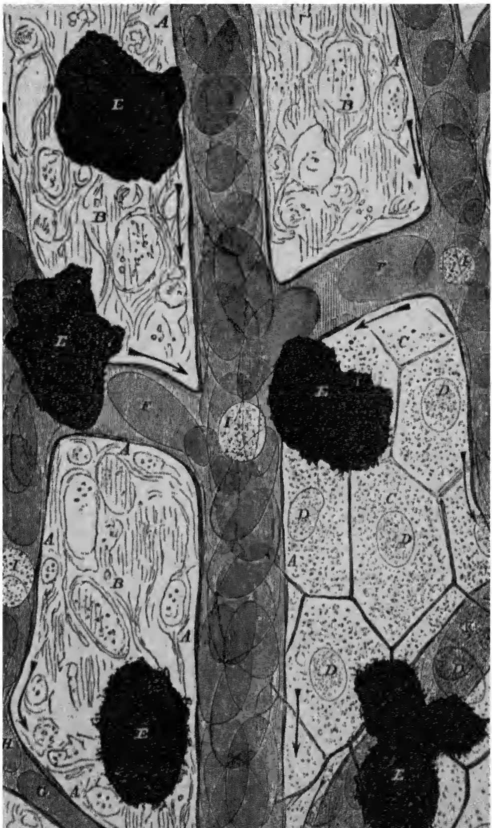

FIG 31 —The circulation in the Frog's web, under a high power , wall of capillaries ; *B*, tissue of the web in which the capillaries lie , *C*, epidermis cells ; *D*, their nuclei , *E*, pigment-cells , *F*, red corpuscles , *G*, *H*, red corpuscles being squeezed through a narrow capillary , *K*, capillary seen through the epidermis ; *I*, colourless corpuscles (From Huxley's *Physiology*)

of the intestine into the smallest possible particles, it will be found that the process has detached numerous, minute, conical bodies, about $\frac{1}{30}$ mm. ($\frac{1}{750}$ in.) in length, polygonal in transverse section, and having one end flat and the other more pointed (Fig. 32). These bodies are called *epithelial cells:* in the natural position they lie closely cemented to one another, like the blocks of a wood-pavement, their flattened ends facing the cavity of the intestine, while their narrower ends abut against the submucosa (p. 73). Thus the epithelial cells together form an *epithelium* or *epithelial layer* of the mucous membrane directly bounding the cavity of the enteric canal.

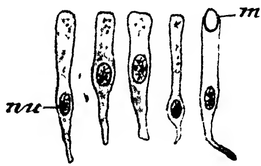

FIG 32.—Columnar epithelial cells from the Frog's intestine. (× 500.) *m* droplet of mucus exuding from cell; *nu* nucleus

Each cell consists of protoplasm and contains a rounded, granular nucleus (*nu*), which is made very conspicuous by staining, and in which are one or more small bodies or *nucleoli*. Certain of these cells have a space towards their free ends containing slime or *mucus*, and thus have the form of little cups or goblets: they are known as *goblet-cells* (*see* right hand cell in Fig. 32).

FIG. 33.—Ciliated epithelial cells from the mucous membrane of the frog's mouth. (× 500.) (From Parker's *Biology*, after Howes.)

Ciliated Epithelium.—By the same method the mucous membrane of the mouth is also seen to be lined by an epithelium, but the cells comprising it (Fig. 33) are broader in proportion to their length, and each is produced on its free surface into a number of delicate, transparent threads of protoplasm called *cilia*, which in the living condition are in constant movement, lashing backwards and forwards like minute

whip-lashes, or, more accurately, like the blades of grass in a field when acted upon by a strong wind. If you happen to get under the microscope a good-sized bit of mucous membrane with the cells in position, you will see that the cilia produce a strong current by which small particles are swept along, while detached cells swim about, like little independent animals, by the action of their own cilia. These *ciliated epithelial cells*, like the ordinary *columnar* cells of the intestine, are made of protoplasm, and each contains a nucleus with one or two nucleoli clearly brought into view by staining.

The action of the cilia can be demonstrated, on a large scale, by placing a freshly-killed frog on its back, turning back or cutting away the lower jaw, and placing a very small cube of cork on the roof of the mouth near to the projection due to the eyes. The cork will be slowly swept back towards the throat.

Squamous or Pavement Epithelium.—By scraping the outer surface of a piece of skin with a sharp knife, and examining the scrapings in a drop of water, after staining them, the superficial layer of the skin will be found to be made up of ned, roughly hexagonal plates (Fig. 34 and Fig. 31, C, D) set closely together, like the tiles of a mosaic pavement. Each plate has a nucleus, and, from its flattened form, is distinguished as a *squamous* or scale-like epithelial cell.

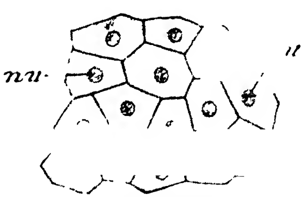

FIG 34 -Squamous epithelial cells from the Frog's skin. (× 300) *nu* nuclei.

Meaning of the word "Cell."—We see thus that the body of the frog is partly made up of distinct elements, which, under a considerable diversity of forms, exhibit the same essential characters. Each structure consists

of a mass of living *protoplasm*, which appears almost clear or more or less granular, containing in its interior a rounded body, the *nucleus*, specially distinguished by the affinity of parts of its substance for colouring matters. To a body having this essential structure, whatever its form, the name *cell* is applied.

Unstriped Muscle.—Examination of a teased preparation of the muscular coat of the intestine, stomach, or urinary bladder will show that it is composed of delicate fibres (Fig. 35) tapering at both ends, and each with a nucleus in the middle. These are called *smooth* or *unstriped muscular fibres:* they are obviously cells which have undergone a great elongation in length.

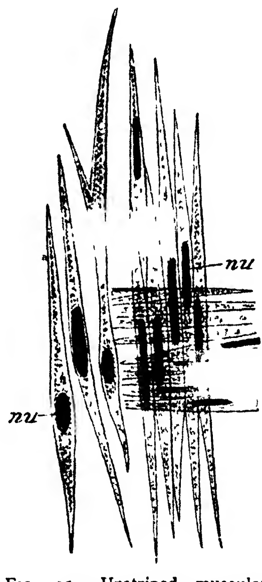

FIG 35.—Unstriped muscular fibres from the Frog's intestine (× 500)
To the right are shown fibres from the longitudinal and circular layers (see Chap VIII) crossing one another; to the left isolated fibres (After Howes)

During the peristaltic movements of the intestine (p. 79) each fibre alternately contracts and relaxes, becoming shorter and thicker during the former process, like the large muscles of the body (p. 64). The movements in this case, however, are not under the control of the will, and unstriped muscular tissue is therefore often spoken of as *involuntary muscle*.

Contractility of Protoplasm.—We have now studied three different kinds of movement in cells:—*muscular movement* in the unstriped muscle-fibres, *ciliary movement* in the ciliated epithelial cells, and *amœboid movement* in the

colourless blood-corpuscles. Muscular movement is due to the fibre undergoing a sudden shortening in a particular direction and a consequent approximation of its two ends. Ciliary movement is due to the alternate bending and straightening of the cilia; and the bending of a cilium in a particular direction is caused by the protoplasm of which it is composed shortening or contracting on the side towards which it bends. Amœboid movement is the protrusion and withdrawal of irregular processes of the cell: this results from the protoplasm undergoing a contraction or squeezing in a given direction, as a consequence of which one part of its substance is drawn in and another pushed out. Hence all three kinds of movement are movements of *contraction;* and *contractility*, or the power of contraction, may be considered as a general property of protoplasm.

Striped Muscle.—If a small piece of any of the body-muscles is carefully teased out with the grain, *i.e.*, in the direction of the length of the fibres, so as to break away the connective-tissue binding them together, the fibres, which are much larger than those of smooth muscle, will readily separate from one another, and they will be seen to be long and cylindrical. Under the microscope each fibre shows a delicate transverse striation (Fig. 36), being made up of alternate bright (*b*) and dim (*d*) bands—or more accurately discs, the fibre being cylindrical—set at right angles to its length. Hence the ordinary body-muscles or *voluntary muscles* are composed of *striped muscular fibres*.[1] In addition to the transverse striation a fainter longitudinal striation is more or less distinctly visible.

Each fibre is covered by a delicate membrane (*s*),

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[1] The muscles of the heart, although not under the control of the will, are transversely striated; but their structure differs from that of ordinary striped voluntary muscle.

the region of the bony partition in such compound bones as the radio-ulna or tibio-fibula (Fig 15, B, D, *p*).

Summary.—The various *simple tissues* studied in the present chapter consist either entirely of cells, or of cells separated by an intercellular substance. Formed entirely of cells are the various kinds of epithelium—columnar, ciliated, and squamous, and unstriped muscle. In striped muscle the cells have elongated into fibres and their nuclei have multiplied. Of the supporting tissues, consisting characteristically of cells with intercellular substance, connective-tissue has the matrix soft and homogeneous, with fibres imbedded in it; in hyaline cartilage it is structureless and tough, though elastic; and in bone laminated and calcified. In the blood, the plasma may be looked upon as a kind of liquid intercellular substance.

Cells, wherever they occur, have the same essential structure, being formed of protoplasm with a nucleus. In nearly all cases they increase by binary fission, first the nucleus and then the protoplasm dividing into two.

The distribution of the various tissues throughout the body is worth noting. Epithelium always bounds a free surface—*e.g.*, that covering the outer surface of the body or lining the inner surface of the enteric canal. Striped muscle forms the "flesh," unstriped muscle the outer layer of the enteric canal (p. 73). Bone and cartilage form the framework of the body, while connective-tissue is the packing between the other tissues.

PRACTICAL DIRECTIONS

General Structure of the Compound Microscope.—The compound microscope, with which you must now become acquainted, consists of a strong *stand* (Fig. 42, *a*) from which rises a vertical *pillar* (*b*) To the latter are attached—a horizontal plate or stage (*c*), perforated in the centre with an aperture (*d*), the size of which can be varied by means of a *diaphragm* : an adjustable *mirror* (*e*), placed below the stage and a vertical *tube* (*f*) attached above the stage by a horizontal arm. Two combinations of lenses are used ; an *objective* or object-glass (*h*), consisting of a metal tube with two or more lenses fixed into it, which screws into the lower end of the tube and an *ocular* or eye-piece (*i*), consisting of a metal cylinder with a lens at each end which slides into the upper end of the tube It is this arrangement of lenses which forms the essential feature of the compound microscope · the object, placed on the stage, is magnified by the objective, and the magnified image, thrown into the interior of the tube, is further enlarged by the ocular.

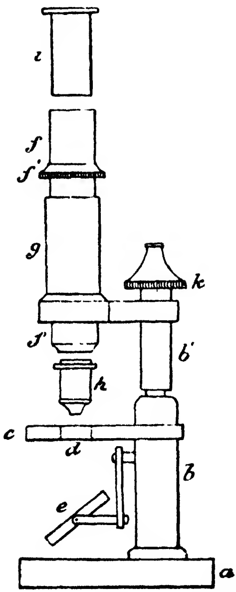

FIG. 42.—Diagram of compound microscope
a. stand, *b* pillar; *b'*. movable portion of pillar, raised and lowered by fine adjustment, *c*. stage, *d*. aperture in stage, *e* mirror; *f* tube; *f'* milled ring for raising and lowering tube; *g*. collar; *h*. objective; *i*. ocular; *k*. screw of fine adjustment.

The object is *brought into focus*—*i e*, placed at such a distance from the objective that a perfectly clear and well-defined image is obtained—in one of two ways. The tube can be raised or lowered either by sliding it up and down in an outer tube or collar (*g*), or, in the more expensive instruments, by a rack and pinion · this movement forms the *coarse adjustment*. In addition, all good micro-

scopes have a *fine adjustment*, usually consisting of a spring concealed in the pillar, and acting upon the horizontal arm which carries the tube it is worked by a screw (*k*), and by means of it the tube can be adjusted to within $\frac{1}{10000}$th of an inch.

When the object is transparent—as in most cases with which we shall have to deal—it is placed over the hole in the stage on a glass slide, and illuminated from below by adjusting the mirror until a beam of light from the window or lamp is reflected vertically upwards: a small hole in the diaphragm should be used with the high power. The object is thus said to be viewed by *transmitted light*. In the case of opaque substances the mirror is not used, and the object is illuminated by the light falling upon it directly: it is then said to be viewed by *reflected light*.

A student's microscope should have two objectives, one—the *low power*—magnifying about 80, the other—the *high power*—about 300 to 400 diameters. One eye-piece is sufficient, and a sliding coarse adjustment is nearly as convenient as a rack and pinion, besides being cheaper and less likely to get out of order. The mistake often made in choosing a microscope is to get one of elaborate construction, the money going largely in brass-work. The proper thing is to get the simplest form of stand consistent with perfect rigidity, fitted with the best possible fine adjustment and lenses. to save on either of the latter is false economy.

Requisites for Microscopic Work.—In addition to the microscope, the following will be required before starting work —

1. A few *slides* or *slips* of glass, 3 inches long by 1 inch wide, which can be obtained from an optician. They must be thoroughly cleaned before being used.

2. A supply (about $\frac{1}{2}$ oz.) of *cover-glasses*, small pieces of very thin glass, to be had at the optician's. The most convenient size is $\frac{3}{4}$ inch square. They are best cleaned by being soaked for a few minutes in strong nitric acid, and then thoroughly washed under the tap, after which they should be dried by being rubbed between the folds of a handkerchief. The thumb should be rubbed against the finger from side to side only, as the slightest pressure from above downwards will break the cover-glass.

3. One or two thin *glass rods*, about 6 inches long and $\frac{1}{8}$th inch in diameter; and one or two *dipping tubes*, or pieces of glass tubing about 6 inches long and $\frac{3}{16}$th inch in diameter

The ends both of rods and tubes should be smoothed off in the flame of a blow-pipe.

4. Three or four *dissecting needles*, made by sticking a fine sewing needle into the end of a wooden penholder, allowing the point to project about half an inch

5. A few *reagent-bottles* for holding the various fluids used for applying what are called *micro-chemical tests* to the tissues Special bottles can be bought for the purpose, but sufficiently convenient ones can be made from ordinary one-ounce phials, fitted with sound corks. Bore a hole lengthwise through the cork, and insert into the hole a piece of narrow glass rod, pointed at the end, just long enough to reach nearly to the bottom of the bottle when the cork is inserted. This arrangement allows of the ready application of a single drop of fluid to the object under examination.

6. The following micro-chemical reagents:

a *Salt solution.* Dissolve 0 75 gramme of sodium chloride in 100 c.c of distilled water, so as to make a $\frac{3}{4}$ per cent solution

b. *Acetic acid*, 1 per cent. One c c of strong acetic acid to 99 c.c. of distilled water.

c. *Distilled water*

d. Solutions of one or two aniline dyes. For fresh tissues, dissolve enough *methyl-green* in distilled water to make a deep bluish-green solution, and add a trace of acetic acid. For preserved (or fresh) tissues, make a saturated solution of *magenta* or *safranin* in strong alcohol, and dilute with an equal bulk of water.

e. *Glycerine*, 50 per cent Equal parts of pure glycerine and distilled water

Microscopical Examination of the Simple Tissues.

For the following work, a freshly-killed frog must be used

(If you wish to measure each kind of tissue-element, you must learn to use a *micrometer*, which consists of a circular piece of glass, marked at regular intervals with lines or squares, the distance between which can be calculated by comparing them with a scale engraved on a slide known as a *stage-micrometer*.)

1. **The Blood.**—Have ready a clean dry slide and cover-glass. In a freshly-killed frog open a vein or make an incision in the heart, and with a clean glass rod remove a drop of blood to the middle of a slide. Take hold of the edge of the cover-glass with small forceps, and supporting it with a mounted needle, gently lower it on to the drop of blood until the latter is spread out into an even, transparent,

yellowish film. This operation of covering the drop of blood requires a little practice : if not done quickly (unless a drop of salt solution is added), there is danger of the blood coagulating before it is covered, in which case it will not spread out into a transparent layer : if the cover is lowered too suddenly, bubbles of air are commonly included.

Examine your preparation, first of all, under the low power, and learn to recognise the appearance of air-bubbles. Note the colourless *plasma* and the numerous minute *blood-cells* or *corpuscles*.

Now replace the low by the high power. Bear in mind that the higher the power the shorter the focal distance. With the low power you will probably find that the object is in focus when about half an inch from the bottom lens of the objective. The high power, on the other hand, has to be brought to within about $\frac{1}{20}$th of an inch of the cover-glass, which is therefore liable to be broken and the lens to be injured by careless focussing The safest plan is to screw down the tube, keeping your eye at the level of the stage, until the objective almost touches the cover-glass . then, looking through the microscope, very slowly raise the tube by means of the coarse adjustment, until the object comes into view. Note (Fig. 30) —

a. The numerous flat, oval, *red corpuscles*, each with a central swelling in which the *nucleus* is contained. Sketch.

b. The *colourless corpuscles* or *leucocytes*, much less numerous, having a granular appearance, and an irregular or rounded outline.

Focus a colourless corpuscle under the high power, and note its *amœboid movements* . sketch its outline rapidly but accurately, and after a minute or two make another sketch, and then another, until some half-dozen outline drawings of the corpuscle have been obtained . then compare your sketches.

Now place on the slide, against one edge of the cover-glass, a drop of methyl-green, and against the opposite edge a small strip of blotting paper. If the blood is sufficiently fresh—and if it has coagulated you must get another drop —the blotting paper will slowly absorb the blood on one side, and the methyl green will be drawn in and will gradually mingle with the blood. When this has taken place, put a drop of salt solution in the place of the methyl-green, and allow it to be drawn across so as to remove the superfluous stain : then remove the blotting paper, and examine the blood once more under the high power. Notice the *nucleus*

present in each kind of corpuscle, and the surrounding *protoplasm* Sketch.

To a fresh drop of blood add, in the same manner, a drop of 1 per cent. acetic acid Note that the body of each corpuscle becomes transparent, while the nucleus is rendered distinct.

To another drop of blood add distilled water. The corpuscles become swollen up and partly dissolved, and the colouring matter (*hæmoglobin*) of the red corpuscles is dissolved out into the plasma

Examine some coagulated blood under the microscope, and note the threads of *fibrin* in which the red corpuscles are entangled, and the *serum*

Examine once more the circulation in the web (p. 109), using the high power, and follow the course of both red and colourless corpuscles through the vessels and capillaries By focussing to the surface of the web the flattened epithelial cells of the epidermis or outer skin can be seen, and at a deeper level the black pigment-cells (see p. 136, and compare Figs. 28 and 31).

2. **Columnar Epithelium.**—Take a small piece of frog's intestine, and place it for 24 hours in a mixture called *Ranvier's alcohol,* consisting of one part of methylated spirit and two parts of water With fine scissors snip off a very small piece—not larger than a pin's head—from the inner surface of the mucous membrane, place it on a slide in a drop of water, and with two dissecting needles tease it out by tearing it into the smallest possible particles The operation is best done under a lens Then put on a cover-glass, and examine first with the low and then with the high power. (Remember that a cover-glass must *always* be used with the high power)

Note the minute, more or less conical cells of *columnar epithelium* (Fig. 32), each containing a *nucleus*. Observe the *goblet-cells* amongst the ordinary columnar cells. Stain with magenta, which is more effective than methyl-green in specimens previously treated with alcohol, add a trace of acetic acid, wash with water (salt solution need only be employed in the case of fresh tissues), and add glycerine. Sketch.

3. **Ciliated Epithelium.**—Snip off a very small bit of mucous membrane from the roof of the mouth cavity of a recently-killed frog, near the eye-ball, and tease it out in salt solution (Fig. 33).

Note the form of the cells and their nuclei: they are relatively shorter than the columnar cells just examined, and

each bears a number of delicate vibratile *cilia* at its free end. Observe the movements of the cilia. Sketch.

Treat with methyl-green, magenta, or acetic acid, when the nucleus will become more apparent.

Perform experiment described on p. 116 to show the action of the cilia as a whole in the entire animal.

4. **Pavement or Squamous Epithelium.**—For some time keep a living frog in a cup of water covered by a plate, and then remove it. In the water will be found plenty of the surface castings of the skin in the form of a white, transparent membrane. Cut off an extremely small piece of this membrane and mount on a glass slide in a drop of water. Examine after treating it with methyl-green. *Or*, if the surface castings have been collected previously and preserved in formaline, stain the preparation with magenta (Fig. 34).

Note the flattened cells fitting together like tiles in a pavement, each one with its nucleus. Sketch.

5. **Unstriped Muscle.**—Snip off a small piece from an inflated urinary bladder of a frog which has been preserved in formaline, wash with water, and mount. *Or*, snip off a very small piece—not bigger than a pin's head—from the muscular coat of the intestine or stomach (or from a urinary bladder) which has been in Ranvier's alcohol for at least twenty-four hours; then tease out in a drop of water very thoroughly. Note the elongated unstriped muscular fibres tapering at both ends, each containing a nucleus (Fig. 35). Stain with magenta. Sketch.

6. **Striped Muscle.**—Snip off a small piece—about ⅛th inch long—from any of the body-muscles of a freshly-killed frog, or, better still, from the muscles of the leg of any insect, for example, a wasp, put it on a slide in a drop of salt solution, and tease it out with the grain, *i.e.*, in the direction of the length of the fibres, by inserting the points of two mounted needles and drawing them apart. The fibres will readily separate from one another: the teasing process must be stopped as soon as they are apart, and care must be taken not to tear or crush the individual fibres, which are large enough to be readily distinguishable with a magnifying-glass.

Observe under the low power of the microscope the long cylindrical fibres (Fig. 36, A), bound together by connective-tissue, and showing a distinct *transverse striation* and a less distinct longitudinal striation. Examine a single fibre under the high power (Fig. 36, B), and make out the *sarcolemma* and the numerous *nuclei*, which will be rendered more

distinct by the addition of acetic acid or by staining. Sketch.

7. **Connective-tissue.**—Carefully separate two of the muscles of the leg in a fresh frog, and note the delicate web of connective-tissue between them : *or*, note the fine strands of connective-tissue between the skin and the muscles of the body-wall. With fine forceps lift up a small shred of this, snip it off with scissors, and place it on a dry slide. Then, with two needles, spread it out on a thin, even layer, breathing on it occasionally to prevent drying. Lastly, place a drop of salt solution on a cover-glass and quickly lower it on the preparation. The reason for this procedure is that if connective-tissue is placed in fluid, it contracts into a little lump, which is too opaque for examination and cannot be readily spread out.

Examine first with the low and then with the high power, and note the bundles of *white fibres*, and the *elastic fibres* (Fig. 37). Sketch.

Add acetic acid : the white fibres swell up, the elastic fibres are more readily distinguished, and the *connective-tissue cells* seen : the latter and the delicate ground-substance will be rendered more distinct by staining. (For comparison, mount in salt solution a piece of one of the fine tendons of the toes : treat as before, and examine.) Sketch

8. **Cartilage.**—Snip off the thin edge of the omo- or xiphisternum or supra-scapula and examine it as before in a drop of salt-solution. *Or*, cut a thin section of the head of the humerus or femur with a razor

Note the transparent, homogeneous *matrix*, containing numerous *lacunæ*, in each of which is a nucleated *cell*. observe here and there the groups of cells formed by binary fission (Fig. 38). Stain, and sketch.

9. **Bone.**—For the examination of dried bone, cut a very thin slice of one of the long bones with a fret-saw : fasten it to a slide with Canada balsam (p. 144) and when the balsam has dried quite hard, rub down the section on a hone until it is thin enough to be quite transparent. *Or*, a transverse section of a bone from a larger animal may be prepared in the same way or bought from a dealer in microscopic objects.

a. Examine first a transverse section of dry frog's bone (*e.g.*, femur or humerus), and note the *marrow-cavity*, the *lamellæ*, and the *lacunæ* and *canaliculi* ; the last two will probably appear black (p. 123 and Fig. 39). A section of human bone, such as is usually supplied ready prepared, or of the bone of some other larger animal, shows a more

complicated structure: instead of a single system of lamellæ, the bone consists of a number of such systems, each surrounding a central canal, in which blood-vessels and nerves run (Fig. 41). Sketch.

b. Compare with a section of decalcified frog's bone,[1] and notice—the fibrous *lamellæ* arranged in two layers, the outer of which is closely invested by the *periosteum*; the *lacunæ*, containing bone-cells; and the outer and inner layers of *osteoblasts* (Fig. 40). Sketch.

(For the histology of *nervous tissue*, see Chapter X.)

[1] The method of preparing sections of this and other tissues will be described at the end of the next chapter (p. 145).

CHAPTER VIII

THE FROG (*continued*): THE MICROSCOPIC EXAMINATION OF THE COMPOUND TISSUES—GLANDS—SECRETION AND ABSORPTION

WITH the exception of the tissues of the nervous system, which will be described in Chapter X, we have now studied the principal simple tissues by the method of *dissociation*, *i.e.*, by separating their constituent parts. We have now to consider the way in which these tissues are combined in the various organs, and for this purpose must adopt some method of examination by which they are seen in their natural relations.

The method adopted for this purpose is that of *section-cutting*. You know how, by cutting sections, in various directions, of a bit of twig, the arrangement and natural relations of its various parts—wood, bark, and pith—can be ascertained. The same thing applies to the organs of the frog and other animals, but, owing to their soft and non-resistant texture, it is impossible to cut them into sections thin enough for microscopic examination without special preparation. The methods employed are by no means easy for the beginner, especially without verbal instruction and the resources of a biological laboratory; but in the event of your wishing to make the preparations described and figured in this chapter for

yourself, the directions given on pp. 144—148 are simple enough to be carried out with very limited appliances.

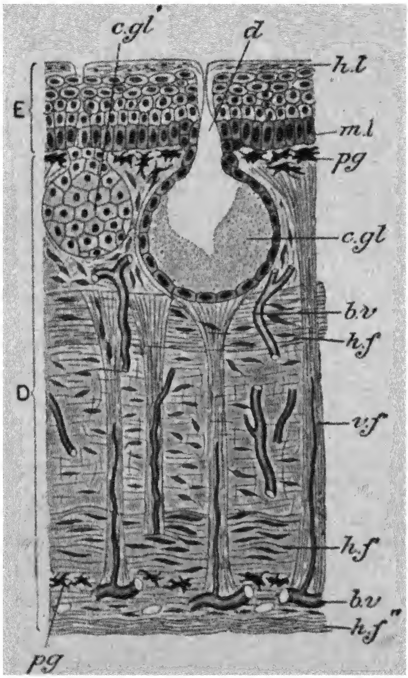

FIG 43.—Vertical section of the Frog's skin, highly magnified. (× about 200) D dermis formed of *hf*, *hf*,' *hf*'' horizontal, and *v f*. vertical fibres of connective-tissue, and containing *b v* blood-vessels, and *pg* pigment cells. E epidermis with *m. l* active or Malpighian layer, and *h l* horny layer of epithelial cells; *c gl* cutaneous gland in section; *c. gl'* in surface view, *d* duct (After Howes)

The Skin.—A vertical section of the skin, *i.e.*, one taken at right angles to its surface, will be seen to have the following structure.

The skin is clearly divisible into two layers, an outer,

the *epidermis* (Fig. 43, E) and an inner, the *dermis* (D). The epidermis is built up of several layers of epithelial cells. These differ greatly in form according to their position, those in the lower or internal layer (*m. l*) being columnar, while those in the upper or external layer (*h. l*) are squamous, and have their protoplasm converted into horny matter so as to furnish a comparatively hard and insensitive covering to the body.

The horny layer is cast off periodically in shreds, and to make up for this, the cells of the inner, or deep, layer multiply by binary fission, the increase in their number necessarily resulting in a pushing upwards of the superjacent layers. There is thus a constant travelling of cells from the inner to the outer surface of the epidermis: as they pass towards the outer surface they become more and more flattened, and at last squamous and horny. The whole process takes place in such a way that the multiplication of the columnar cells in the lower layer is just sufficient to make good the loss of the squamous cells in the superficial layer.

The dermis (D) is formed of connective-tissue, the fibres of which are mostly horizontal (*h. f*, *h. f'*, *h. f''*), or parallel to the surface of the skin, but at intervals are found bands of vertical fibres (*v. f*). The dermis also differs from the epidermis in having an abundant blood-supply (*b. v*), capillaries ramifying through it in all directions. It also contains nerves, the ultimate fibres of which have been traced into the deeper layers of the epidermis. Imbedded in the dermis, especially in its external portion, are irregular cells (*pg*), the protoplasm of which contains pigment, often appearing intensely black. It is to these *pigment-cells* that the coloured patches in the frog's skin are due (Figs. 28 and 31).

In this as well as in the other sections described in

dermis, its deeper part being called the *submucosa* (*see* p. 73). The epithelium consists of a single layer of cells only (B, *ep*), all columnar, and with their long axes at right angles to the elevations into which, as we have seen (p. 73), the mucous membrane is thrown. Amongst the ordinary epithelial cells numerous mucus-secreting goblet-cells will be recognised. The submucosa, like the dermis, contains blood-vessels, lymphatics, and nerves.

The muscular layer (A, *m*) is also divisible into two: an outer layer of *longitudinal fibres* (B, *l. m*), running parallel with the long axis of the tube, and an inner, much thicker layer of *circular fibres* (*c. m*) which encircle it, and consequently lie at right angles to the longitudinal fibres. Thus in a transverse section, such as Fig. 44, the fibres of the circular layer are cut longitudinally, those of the longitudinal layer transversely, while the opposite would be the case in a longitudinal section.

The peritoneum (*pr*), which, as we have seen (p. 26), forms an outer covering to the intestine, is formed of a thin inner layer of connective-tissue and an outer of squamous epithelium.

The Stomach.—Transverse sections of the stomach (Fig. 45) show it to differ from the intestine not only in the much greater thickness of all its layers, but also in the fact that the epithelium, instead of simply forming an even layer over the ridges of mucous membrane, is sunk into the mucous membrane in the form of simple or branched tubes, the *gastric glands* (*g. gl*). These differ from the cutaneous glands in being not flask-shaped but test-tube-shaped, each being a narrow tube, with an extremely small cavity (B an[illegible], *c*). They are lined by a single layer of gland-cells, and open by minute apertures (*m*) on the surface of the mucous membrane.

The cells of the gastric glands have the power of forming, out of the materials supplied to them by the blood, the gastric juice, by which, as we have learnt (p. 77), proteins are digested. Thus, while the raw material supplied to both cutaneous and gastric glands

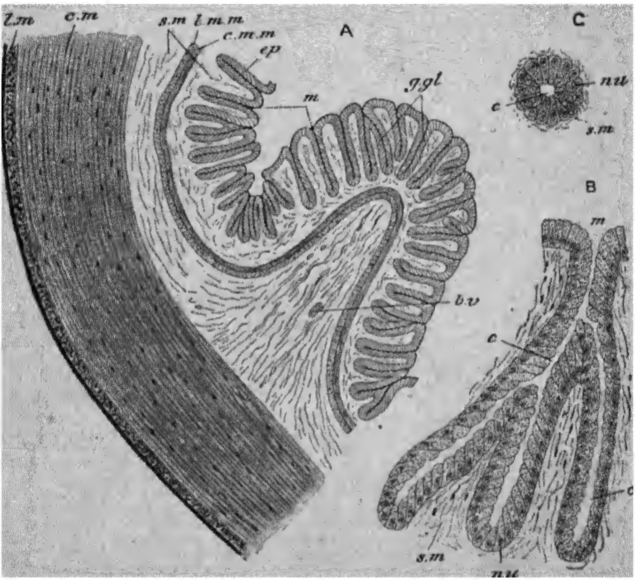

FIG 45 —A, part of a transverse section of the Frog's stomach (× about 50); B, one of the gastric glands in longitudinal section (× about 300); C, transverse section of a gastric gland

b. v blood-vessel; *c* cavity of gastric gland, *c. m* circular muscles; *c m m* circular layer of muscularis mucosæ; *ep* epithelium, *g gl* gastric glands; *l. m* longitudinal muscles, *l m. m.* longitudinal layer of muscularis mucosæ, *m* mouth of gastric gland; *nu* nucleus, *pr* peritoneum, *s m* sub-mucosa.

is the same, the manufactured article is entirely different in the two cases. Each kind of gland-cell has the faculty of picking and choosing, the material supplied being worked up in the one case into the cutaneous secretion, in the other into gastric juice.

The liver-cells are glandular and secrete the bile, which, as it is formed, exudes into the bile-passages and passes into the hepatic ducts, thence making its way either directly into the intestine or into the gall-bladder (p. 72). The whole liver, which is the largest gland in the body, is traversed by a complex network of capillaries (*bl*), arising partly from the hepatic artery, partly from the hepatic portal vein; and from the blood thus supplied, the liver-cells obtain the materials necessary to enable them to discharge their function of secreting the bile.

The liver-cells have, however, other functions, one of which is to manufacture a substance called *glycogen*, or animal-starch, out of sugar absorbed in the intestine and brought to the liver by the blood in the portal vein. This is stored up in the cells in the form of minute insoluble granules, the material of which, being afterwards transformed into soluble sugar, gradually passes into the blood and so to the tissues. A good deal of the excess of amino-acids formed by the digestion of proteins, as also those formed by the oxidation of the proteins of the tissues of the body and carried to the liver in the blood-stream, are changed into urea by that organ.

Connection of the foregoing facts with the Physiology of Nutrition.—You will now be able to understand more clearly the various processes connected with the nutrition of the frog, hitherto studied without the aid of histology

When the food enters the enteric canal the various gland-cells are stimulated into activity, and the gastric juice, bile, and pancreatic juice are poured out and mingled with the food, which is digested in the manner already described. The soluble products of digestion—peptones, amino-acids, sugar, salts, fatty acids, and glycerine—diffuse through the epithelium of the enteric

canal into the blood-capillaries of the underlying submucosa, and the blood, now loaded with nutriment, is carried by the portal vein to the liver and thence by the hepatic and postcaval veins to the heart (see Fig. 27). At the same time the fats make their way into the lymph-capillaries and are finally pumped, by the lymph-hearts, into the veins. Thus the products of digestion all find their way ultimately into the blood, and are distributed, through the circulatory mechanism, to all parts of the body.

PRACTICAL DIRECTIONS

Materials required for the Preparation and Sectioning of Animal Tissues.—In addition to the requisites mentioned in Chapters I and VII, the following will be required :—

a. Corrosive sublimate : a saturated solution in water. Care should be taken in using this solution, as it is a very virulent poison.

b. Absolute alcohol.

c. Turpentine or *xylol.*

d. Paraffin : " hard " and " soft." Get an ounce or two of each

e. A solution of *Canada balsam* in chloroform, xylol, or turpentine. This should be kept in a small glass bottle with a ground glass cap—not a stopper or cork.

f. A solution of *alcoholic borax carmine.* This (like many other useful staining-solutions, such as Ehrlich's *hæmatoxylin*) may be bought ready prepared : or it may be made as follows :—Grind up in a mortar 2 grammes of carmine and 4 grammes of borax, and dissolve in 100 c.c. of distilled water : to this solution add an equal volume of 70 per cent. alcohol : allow to stand for a day or two and filter.

g. A *water-bath*, in which melted paraffin may be kept at a constant temperature.

h. Two or three *watch-glasses* or other small shallow vessels for containing melted paraffin.

i. A sharp, flat-ground *razor.*

j. A *section-lifter*, made by beating out flat about half an inch of the end of a piece of stout copper wire, about 6 in.

long, and bending the flattened portion at an obtuse angle with the rest.

Preparation of Tissues for Section-cutting.

a. Fixing, hardening, and decalcifying.

Sections may be cut from specimens which have been carefully preserved in alcohol :—first in 70 per cent, and after a day or two transferred to 90 per cent. But certain other reagents are more effective for the purpose of *fixing* the tissues—*i.e.*, quickly killing and coagulating the protoplasm of the cells with a minimum of shrinkage,—and of these the one most generally useful is a solution of corrosive sublimate (see *a*, above), in which, from a freshly-killed frog, place small pieces of the various organs and tissues to be examined—*e g*, skin, intestine, stomach, liver, pancreas, kidney, ovary, spermary, and spinal cord, as well as the inner half of the eye-ball. The intestine and stomach should be first washed out in salt solution, and then cut into pieces about ⅜ inch long; the liver should be cut into pieces not more than ¼ inch cube. After about half-an-hour to two hours, according to the size of the piece, place in water under a tap, and wash thoroughly for a quarter of an hour or more, until the corrosive sublimate is removed.

After washing, transfer to 50 per cent. alcohol for a few hours, and then to 70 per cent. for twenty-four hours, after which the pieces may be stained at once (*see* below), or transferred to strong methylated spirit (90–93 per cent), in which they may be kept until wanted. This completes the process of *hardening* : it is done gradually, by alcohols of increasing strength, in order to avoid shrinkage.

In order to *decalcify* such tissues as bone, from which the lime-salts must be extracted before cutting into sections, place a small piece for a few days in 70 per cent. alcohol to which 2 per cent. of strong nitric acid has been added : then wash thoroughly, transfer to alcohol, and stain.

b. Staining.—Place the organs, cut into convenient sizes for imbedding—*i.e.*, not more than ¼ inch long, and, in the case of such organs as the liver, ⅛ inch in thickness—into borax-carmine or hæmatoxylin for one or two days or even more. They will become stained throughout, and the difficulty of staining the sections after cutting will thus be avoided. After staining, place them in weak alcohol (50–70 per cent.), slightly acidulated with hydrochloric acid : if a watch-glass or some such vessel is used, it is sufficient to dip the end of a glass rod into acid and stir it round in the alcohol. The effect of the acid is to remove much of the colour from

the protoplasm of the cells, leaving the nuclei brightly tinted. After half-an-hour or less in the acid alcohol, place the tissues once more in strong methylated spirit.

c. Dehydrating.—Transfer from the strong methylated spirit to absolute alcohol, which must be kept in a stoppered or tightly corked bottle, as it will otherwise deteriorate by absorption of water from the air It has the effect of withdrawing the last traces of water from the tissues, an absolutely necessary step in order that they may be permeated with paraffin

d Imbedding—Transfer the objects from absolute alcohol to turpentine or xylol. Either of these fluids acts as an intermediary between alcohol and paraffin, being freely miscible with both it gradually replaces the alcohol in the tissues, rendering them transparent If they are not transparent in the course of an hour or so, the process of dehydration has not been complete, and they must be returned to absolute alcohol In the meantime, melt some paraffin over the water-bath, using various mixtures of hard and soft according to the season: in a cold room in winter soft paraffin will be hard enough; in the height of summer hard paraffin alone will be suitable The temperature of the water-bath must never be allowed to rise more than a degree or two above the melting-point of the paraffin. Transfer the objects from turpentine or xylol to melted paraffin and keep them in it for some hours—the time varies according to the size of the piece—until they are thoroughly permeated.

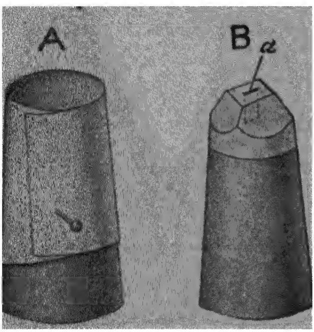

FIG 48 —A, imbedding box made by wrapping paper round a cork, B, cork after removal of the paper, showing the paraffin pared down to a convenient size for sectioning *a*, object to be cut

If you wish to cut sections by hand, get some ordinary medium-sized bottle-corks: around each wind a piece of paper, allowing it to project about ½ an inch beyond one end of the cork, and fixing it with a pin, as in Fig. 48, A. Into the little cylindrical vessel or imbedding box thus formed pour some melted paraffin, and immediately transfer to it, by means of a warmed section-

lifter or forceps, one of the prepared pieces, adjusting its position by means of a heated needle. When the paraffin is quite cold remove the paper, and you will have fixed to the cork a solid block of paraffin containing the object to be cut.

e. Section-cutting —Pare away the block of paraffin until the object comes into view: then trim the block, as in Fig. 48, B, until its upper surface, with the object in the middle, is not more than ¼ inch square. Hold the cork firmly in the left hand, with the wrist resting on the table, and with a razor cut the thinnest possible slices of the paraffin block, including the imbedded object. The razor must be held firmly grasped at the junction of blade and handle, and kept with the surface of the blade parallel with that of the block · use almost the whole length of the edge for each section With a little practice you will be able to cut sections so thin as to be quite transparent under the high power [1]

f. Clearing and mounting —Place the section on a slide and warm it gently on the water-bath until the paraffin melts, and then add a large drop of turpentine or xylol in order to dissolve the paraffin. Then draw off the turpentine with blotting-paper and replace it by a fresh drop, repeating the process until all the paraffin is dissolved . put on a cover-glass and examine

If you wish to be sure that the parts of your sections are not displaced in mounting, or to mount several sections on one slide, the latter should first be smeared over with a very thin layer of a mixture of *collodion* and *oil of cloves*, or of *glycerine* and *white of egg*, in equal parts : then place the sections on the slide, warm, and immerse the whole slide in a small vessel of turpentine or xylol, leaving it until all the paraffin is dissolved.

In order to make a permanent preparation, remove the paraffin with turpentine or xylol, as above, draw off the turpentine, place a drop of Canada balsam on a cover-glass and very gently lower the cover-glass on the object, spreading out the balsam in a thin, even layer. Before

[1] In a properly furnished laboratory sections are cut with a *microtome*, or section-cutting machine, which gives much better results and is absolutely necessary when a complete series of sections of the same object is required. Usually in elementary classes sections are given to the students which have been cut by the teacher with a microtome after being treated and stained in the manner described above. These are usually given out mounted on thin pieces of mica, and can be placed directly in a drop of Canada balsam, and examined after covering with a cover-glass.

long, the balsam will have set quite hard, and the sections may be preserved for an indefinite period : the balsam will set more quickly if you leave your preparations over the water-bath for a short time.

Remember that object, razor, slide, and cover must be kept free from water, the presence of which, from the stage of dehydration onwards, is fatal to success.

Examination of Compound Tissues.

Examine the following sections, prepared as described above, first with the low, and then with the high power, noting the parts enumerated in each case, as well as the structure of the nuclei (*nuclear membrane*, ***chromatin***, and *nucleoli*).

1. **Vertical Section of Skin** (Fig. 43).

a. *Epidermis*, stratified epithelium, divisible into outer *horny*) and inner (*Malpighian*) layers.

b. *Dermis*, connective-tissue fibres, blood-vessels and pigment-cells.

c. *Cutaneous glands* with their *ducts*.

Sketch.

2. **Transverse Section of Intestine** (Fig. 44).

a. *Mucous membrane :* a superficial *epithelial* layer of columnar cells, with goblet-cells amongst them ; and a deeper connective-tissue *layer*, the *submucosa*, enclosing vessels and nerves.

b. *Muscular layer :* an external longitudinal, and an internal circular layer of unstriped muscular fibres.

c. *Peritoneal layer*. This is very thin, and a careful examination of good preparations is required in order to make out its structure (p. 139).

Sketch.

3. **Transverse Section of Stomach** (Fig. 45).—After recognising the layers as above, note :—

a. The *gastric glands*, and *b*. the *muscularis mucosæ*.

Sketch.

4. **Sections of Pancreas** (Fig. 46).

a. *Lobules*, separated by connective-tissue, and each consisting of *gland-cells* ; *b*. *ducts*.

Sketch.

5. **Sections of Liver** (Fig. 47).

a. Polyhedral *gland-cells*, arranged in columns ; *b*. *bile-passages* and *ducts* ; *c*. *blood-capillaries* and *vessels*.

Sketch.

escape in one way only, viz., through the glottis into the lungs.

Thus *inspiration*, or breathing-in, is produced by the buccal cavity acting as a force-pump ; the lowering of its floor draws in air through the nostrils, the raising of its floor forces the imprisoned air into the lungs.

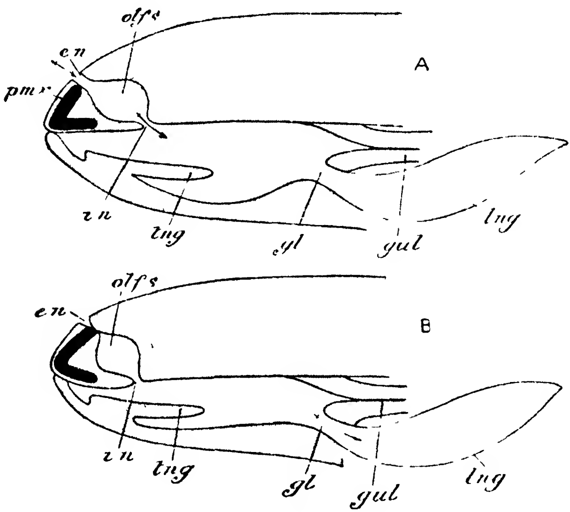

FIG 50 —Diagrams illustrating the respiratory movements of the Frog (× 2) In A the floor of the mouth is depressed and air is being drawn in through the nostrils, in B the floor of the mouth is raised, the nostrils are closed, and air is being forced into the lungs
e n. external nostril, *gl* glottis, *gu'* gullet, *i n* internal nostril, *lng.* lung, *olf s.* olfactory sac, *pmx* premaxilla, *tng* tongue

Expiration, or breathing-out, is due to a contraction of the elastic lungs, accompanied by a slight lowering of the tip of the lower jaw: the latter movement releases the premaxillæ and thus opens the external nostrils.

Respiration.—By the alternate movements of inspira-

tion and expiration, fresh air passes into the lungs at regular intervals, while part of the air already contained in them is expelled. Now we saw, when studying the blood (p. 84), that dark purple blood drawn from a vein becomes bright scarlet when exposed to air, and we subsequently learnt (p. 113) that this change is due to the absorption of oxygen by the red corpuscles.

The blood brought to the lungs by the pulmonary artery is, as we have seen (p. 99), non-aërated, being the impure blood returned by the three caval veins to the right auricle. When this blood is pumped into the capillaries of the lungs it is separated from the air contained in those organs only by the extremely thin walls of the capillaries themselves and the equally delicate pavement epithelium lining the lungs (p. 150, and Fig. 27, *Cp. lng, Ep. lng*). Under these circumstances an interchange of gases takes place between the air in the lungs and the gases dissolved in the blood: the hæmoglobin of the red corpuscles absorbs oxygen, and the carbon dioxide in the blood, derived from the waste of the tissue, is given off into the cavities of the lungs. The blood in the pulmonary capillaries thus becomes aërated and is returned as red blood to the left auricle: at the same time it loses carbon dioxide, together with a certain amount of water, and these waste substances are expelled from the body with the expired air.

Voice.—It was mentioned above (p. 149) that the glottis and laryngo-tracheal chamber are supported by cartilages. The largest of these are a pair of semilunar *arytenoid cartilages* (Fig. 49, *ar*), which bound the glottis to right and left. The mucous membrane on the inner or adjacent faces of the arytenoids is raised into a pair—right and left—of horizontal folds, the *vocal cords* (*v. cd*). By means of muscles these folds can be stretched and relaxed, and can be brought into either a

glandular epithelium, which, in some parts (*ur. tu, ur. tu'*), are ciliated. The Malpighian capsules are lined with flattened cells of pavement epithelium.

The arrangement of the blood-vessels is peculiar. Like other organs, the kidney is permeated by a network of capillaries (*cp*) which form a close mesh between the urinary tubules, so that the cavity of the tubule is separated from the blood only by the thickness of the gland-cells and of the capillary wall. The capillary network is supplied partly by the renal arteries (*r. a*), partly by the renal portal vein (*r. pt. v*), and is drained by the renal veins (*r. v*). It is in the behaviour of the renal arteries that the chief peculiarity of the kidney-circulation lies. On entering the kidneys they break up into smaller and smaller arteries, but each of the ultimate branches (*af. v*), instead of discharging into the general capillary network, passes to a Malpighian capsule, in the interior of which it breaks up into a little bunch of coiled capillaries, the *glomerulus* (*gl*). From this the blood is carried off by a minute vessel (*ef. v*) by which it is poured into the general capillary network and finally discharged into the renal vein (*r. v*).

Renal Excretion.—While circulating through the glomerulus, water and certain soluble matters are separated from the blood and make their way into the Malpighian capsule and thence into the urinary tubule. As the blood circulates through the general capillary network, the gland-cells of the tubules excrete, out of the materials brought to them by the blood, the nitrogenous waste matter *urea*, in the formation of which the liver plays an important part (p. 143); it is discharged from the cells into the cavity of the tubule, where it is dissolved in the water separated out of the glomerulus. In this way the *urine* is formed. Accumulating in the tubules, it makes its way into the ureter and thence drop

by drop into the cloaca, whence it is either expelled at once, or stored for a time in the bladder.

Note that the formation of urine is a process of secretion of a similar nature to the secretion of gastric juice, bile, &c. The fluid secreted is, however, of no further use to the animal, and would, in fact, act as a virulent poison if retained in the system. It is therefore got rid of as soon as possible. Secretions of this kind, consisting not of useful but of harmful or waste matters, are distinguished as *excretions*.

Bile is also in part an excretion as it contains pigments due to the disintegration of hæmoglobin, and thus by its means the effete colouring matters of the blood are passed into the intestine and got rid of.

Pulmonary and Cutaneous Excretion.—The lungs, besides being organs of respiration, take their share in excretion, since they get rid of the important waste product, carbon dioxide, together with a considerable quantity of water. Similar functions are discharged by the skin, which is also an organ both of respiration and of excretion. Interchange of gases takes place between the outer air and the blood in the capillaries of the dermis: the carbon dioxide of the non-aërated blood brought to the skin by the cutaneous artery (p. 99 and Fig. 27) is exchanged for oxygen, and the blood, in the aërated condition, is returned by the musculo-cutaneous vein to the heart. Moreover, the cells of the cutaneous glands separate water and other constituents from the blood, and the fluid thus formed is poured out on the surface of the body. Here it serves to keep the skin moist, and is finally lost, either by evaporation or by mingling with the water in which the frog is immersed. The cutaneous secretion has also poisonous properties, and so probably serves as a defence against some of the animal's enemies.

Summary of the Processes of Nutrition.—We are

now in a position to understand the general features of the whole complicated series of processes which have to do with the nutrition of the frog, which are collectively spoken of as *metabolism*. These processes are illustrated in the diagram (Fig. 27, p. 97), which should be constantly consulted in connection with the following summary.

All parts of the body are placed in communication with one another by means of the blood-vessels, through which a constant stream of blood is flowing in a definite direction.

In all parts, waste of substance (*destructive metabolism*) is continually going on, and the waste products—water, carbon dioxide, and some nitrogenous substances which ultimately take the form of urea—are passed either directly into the blood, or first into the lymph and thence into the blood.

At the same time the cells withdraw nutrient materials from the blood, and *assimilate* them, *i.e.*, form new living substance, whereby the waste is made good, and the tissues adequately nourished (*constructive metabolism*). Oxygen is also withdrawn from the blood; like the air supplied to a fire, it is essential to the oxidation or low temperature combustion with which the waste of tissues is associated. By the withdrawal of its oxygen the hæmoglobin of the blood alters its colour from scarlet to purple.

Thus the blood as it passes through the body is constantly being impoverished by the withdrawal of nutrient matters and of oxygen, and as constantly being fouled by the discharge into it of waste products. It reaches the capillaries of an organ as bright red, aërated blood, and leaves it as purple, non-aërated blood.

These changes, by which the blood loses nutrient matters and oxygen and gains waste products, take place all over the body. The converse processes by

Evolution of Heat.—The oxidation of the tissues, like that of coal or wood in a fire, is accompanied by a rise in temperature. But in the frog, as in other cold-blooded animals, the evolution of heat is never sufficient to raise the temperature of the body more than very slightly above that of the surrounding medium. In warm-blooded animals, such as ourselves, the temperature is regulated, according to the season, by a greater or less evaporation of water from the surface of the body. In the frog this is not the case: the temperature of the animal is always nearly the same as that of the air or water in which it lives, and hence the frosts of winter would be fatal to it, but for the habit of hibernation (p. 9).

Death and Decomposition.—The decomposition undergone by a dead frog (p. 12) may be looked upon as an excessive process of waste unaccompanied by repair. Owing to the action of certain microscopic plants known as *Bacteria*, the proteins undergo oxidation, amongst the principal products of which are water, carbon dioxide, ammonia, and certain gases of evil odour, such as sulphuretted hydrogen and ammonium sulphide. Most of the gases escape into the air, while the ammonia is finally converted into nitrous and nitric acids. These, combining with certain substances in the soil, give rise to salts called nitrates and nitrites, which furnish one of the chief sources of the food of plants.

PRACTICAL DIRECTIONS

The Organs of Respiration and of Voice.—Pin down a frog in the usual way (pp. 31 and 32), remove the heart, and make out the precise relation of the lungs, first distending them with air through the glottis. The specimen already used for the dissection of the vascular system or alimentary canal will serve the purpose. Harden thoroughly in for-

maline or spirit and note (Fig 49) the *laryngo-tracheal chamber*, which communicates on the one hand with the pharynx through the glottis, and on the other with both lungs. Observe also the *posterior horns of the hyoid* which embrace the glottis, and then separate them from the laryngo-tracheal chamber, so as to remove the latter, together with the lungs, from the body

Then dissect off what remains of the mucous membrane of the pharynx around the glottis, and notice the small *laryngeal muscles* in connection with the laryngo-tracheal chamber: remove these, and pin the respiratory organs down under water, dorsal surface of the lungs uppermost, by means of a pin through each lung Cut away the ventral wall of one lung, so as to expose the cavity and its connection with the laryngo-tracheal chamber. Note :—

1. The two *arytenoid cartilages*, and a ring-shaped cartilage surrounding the base of the lungs.

2. The *network of ridges* on the inner surface of the lungs Examine with a lens. Sketch

3 The *vocal cords*. Observe these first in their natural position, and then with the scissors cut through the laryngo-tracheal chamber along the line of the glottis so as to divide it into right and left halves and thus expose the vocal cords from their surface Sketch

The Kidneys.—*a* Examine these organs *in situ* (Figs 5, 8, and 25) and note :—

1. Their form and position, and the relations of the peritoneum, which covers them on the ventral side only (See Fig. 6.)

2. The *ureters* (their openings into the cloaca may be seen at a later stage).

3. The yellowish *adrenals*

Sketch

b. Examine under the microscope a transverse section of the kidney, prepared as directed on p. 145, and make out (Fig. 51) :—

1. The *urinary tubules*, cut through in various planes

2. The *Malpighian* (or *Bowman's*) *capsules* and their *glomeruli*.

3. *Blood-capillaries* and *vessels*.

4. The *nephrostomes* (p. 104, Figs. 27, 51, and 52).

Sketch a portion under the high power. Compare with a section of kidney in which the blood-vessels have been injected with coloured gelatine (p 107).

CHAPTER X

THE FROG (*continued*): THE NERVOUS SYSTEM

In a machine of human construction, such as a steam-engine, the proper working of the whole depends, providing the parts of the machine itself are in good order, upon two things—the stoking or regulation of the fires, and the turning of certain cocks and levers by the engineer. In that very complex machine the frog, we have already studied what corresponds to stoking, viz., feeding and breathing. We must now direct our attention to what may be considered roughly to correspond with the work of the engineer—the means by which the whole complex machinery is kept under control, and its various parts made to work together to a common end.

How does it come about, for instance, that the various digestive glands begin to secrete actively as soon as food is taken into the enteric canal? How is it that a touch on any part of the body, or even the sight of an enemy, is followed instantaneously by a series of vigorous muscular movements so ordered as to facilitate escape from the source of danger?

In the fourth chapter (p. 65) we got so far as to learn that muscular contractions are induced by *nervous impulses* travelling from the brain or spinal cord, along the

to the leg, the largest of which, the *sciatic nerve* (*sci*), being that already mentioned in the chapter on the muscular system (p. 65).

The tenth is a very small nerve and in the common Indian frog is very frequently absent altogether, or present on one side only. It emerges when present through a small aperture in the side of the urostyle (p. 39).

It will be noticed that while the large ventral branch of the first spinal nerve—the hypoglossal—supplies muscles only, and is therefore a *motor nerve*, all the others go to both muscles and skin, and are therefore both *motor* and *sensory*, or *mixed nerves*. They all branch out in a complex manner, and are traceable to the remotest parts of the body.

The Sympathetic Nerves.—On either side of the dorsal aorta is a very delicate nerve, having at intervals little swellings called *ganglia*, each of which is connected with a spinal nerve by a communicating branch (Figs. 56 and 58, *s2*—*s9*, *sy*, *rc*). In front of the point where the dorsal aorta (*D. Ao*) is formed by the union of the two systemic trunks (*Ao*), these two *sympathetic nerves*, as they are called, are continued forward, one on either side of the vertebral column, towards the head, when they enter the skull and become connected with certain of the cerebral nerves.

Each sympathetic nerve has altogether nine or ten ganglia, each connected with one of the spinal nerves, and from the ganglia branches are given off which supply the heart and blood-vessels, the stomach, intestine, liver, kidneys, reproductive organs, and urinary bladder.

Origin of the Spinal Nerves.—The mode of origin of the nerves from the spinal cord is peculiar and characteristic. Traced towards the cord, each nerve is found, on

reaching the intervertebral foramen from which it emerges, to divide into two—a *dorsal root* which springs from the dorsal, and a *ventral root* which arises from the ventral region of the cord (Fig. 57, *d.r, v.r*). The dorsal root is distinguished from the ventral by being dilated into a *ganglion* (*gn*). In Fig. 56 these ganglia lie hidden within certain calcareous bodies (*C*) in this region. If the centra of all the vertebræ are removed, it is seen that the spinal cord is a good deal shorter in length than the neural canal which it occupies, and consequently the roots of the seventh, eighth, and

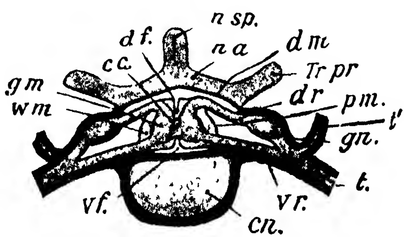

FIG. 57—Transverse section through the vertebral column and spinal cord of the Frog, to show the mode of origin of the spinal nerves (× 6)
c c central canal; *cn* centrum, *d f* dorsal fissure, *d m* dura mater, *d r* dorsal root; *g m* grey matter, *gn* ganglion of dorsal root, *n a* neural arch, *n sp* neural spine; *p m* pia mater; *t* nerve trunk (ventral branch), *t'*. dorsal branch, *Tr pr.* transverse process; *v. f.* ventral fissure, *v. r* ventral root, *w. m.* white matter (After Howes)

ninth nerves have to run very obliquely, in order to pass out of their respective intervertebral foramina. The filum terminale, together with roots of these nerves, presents an appearance not unlike a horse's tail, and the name *cauda equina* is consequently given to them.

Cerebral Nerves.—There are ten pairs of cerebral nerves, some of which are purely sensory, some purely motor, some mixed.

The *first* or *olfactory nerves* (Fig. 54, *I*) arise from the olfactory lobes, and pass through two holes in the trans-

verse partition of the girdle-bone. Each is distributed to the mucous membrane of the nasal sac or organ of smell of the same side, and is purely sensory.

The *second* or *optic* (*II*) is a large nerve which springs from the ventral surface of the diencephalon. At their origin the right and left optic nerves have their fibres intermingled, forming a structure something like a St. Andrew's Cross and called the *optic chiasma* (*opt. ch*), the other limbs of the cross passing upwards and backwards to the optic lobes. The optic nerve makes its exit from the brain-case through the optic foramen, and is distributed to the retina, a delicate membrane which lines the eye-ball, and is, as we shall see, the actual organ of sight. This nerve also is purely sensory.

The *third* or *oculomotor* (*III*) is a small nerve arising from the crura cerebri beneath the optic lobes close to the median line. It passes through a small hole in the side of the skull behind the optic foramen, and supplies four out of the six muscles by which the eye-ball is moved, and is purely motor.

The *fourth* or *pathetic* (*IV*) is a very small nerve leaving the dorsal surface of the brain between the optic lobes and the cerebellum, and making its exit from the skull above the third nerve. It is also purely motor, supplying one of the muscles of the eye—the superior oblique.

The *fifth* or *trigeminal* (Figs. 54 and 58, *V*) is a large nerve arising from the side of the medulla oblongata. Its root dilates to form a ganglion, the *Gasserian ganglion*, and leaves the skull by the large aperture noticed in the pro-otic bone. It owes its name to the fact that it soon divides into three main branches; one, the *ophthalmic* (Fig. 58, V^1), going to the skin of the snout; another, the *maxillary* (V^2), to the upper lip and lower eyelid; and the third, or *mandibular* (V^3),

to the muscles and skin of the lower jaw. The trigeminal is a mixed nerve.

The *sixth* or *abducent* (Fig. 54, *VI*) is a very small motor nerve arising from the ventral aspect of the

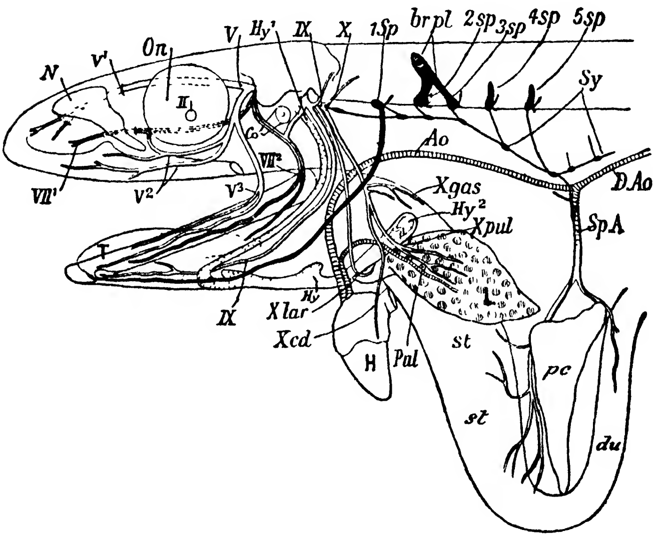

FIG 58.—Dissection of the head and anterior part of the body of the Frog from the left side, to show the distribution of the fifth, seventh, ninth, and tenth cerebral nerves, as well as of the hypoglossal and part of the sympathetic. (× $1\frac{1}{2}$)

Ao. systemic arch, *br pl* brachial plexus, *co* columella; *D. ao* dorsal aorta; *du* duodenum; *H* heart, *Hy* body of hyoid, Hy^1 anterior, and Hy^2. posterior horns of hyoid, *L* lung, *N* olfactory sac, *On* orbit; *Pul* pulmonary artery; *Sp A* splanchnic artery, *st* stomach, *Sy* sympathetic; *II.* cut end of optic nerve, V^1 ophthalmic, V^2 maxillary, and V^3 mandibular branch of trigeminal (*V*), VII^1 palatine, and VII^2 hyomandibular branch of facial; *IX.* glossopharyngeal, *X* vagus, *Xcd* cardiac, *Xgas* gastric, *Xlar.* laryngeal, and *Xpul* pulmonary branch of vagus; *1 Sp* first spinal nerve (hypoglossal), *2 sp.*—*5 sp.* second to fifth spinal nerves. (After Howes, slightly modified)

bulb, close to the median line, and supplying one of the muscles of the eye-ball called the posterior rectus.

The *seventh* or *facial* nerve (Figs. 54 and 58, *VII*) arises just behind the fifth and soon joins the Gasserian

ganglion. Both it and the sixth leave the skull by the same aperture as the fifth. It divides into two branches, one of which, the *palatine* (Fig. 58, *VII*[1]), supplies the mucous membrane of the roof of the mouth, and the other, or *hyomandibular* (*VII*[2]), sends branches to the skin and muscles of the lower jaw and to the muscles of the hyoid. It is a mixed nerve.

The *eighth* or *auditory* nerve (Fig. 54, *VIII*) arise from the medulla just behind the seventh, passes through an aperture in the inner wall of the auditory capsule, and is distributed to the auditory organ or membranous labyrinth (see Figs. 12 and 65). It is the nerve of hearing, and is purely sensory.

The *ninth* or *glossopharyngeal* (Figs. 54 and 58, *IX*) arises behind the auditory nerve. It sends a branch to join the facial, and supplies the mucous membrane of the tongue and pharynx as well as certain small muscles connected with the hyoid. It is also a mixed nerve.

The *tenth* or *vagus* (Figs. 54 and 58, *X*) is a large nerve arising in common with the ninth, and dilating, shortly after leaving the skull, into a *vagus ganglion*. It supplies the larynx (*Xlar*), the heart (*Xcd*), the lungs (*Xpul*), and the stomach (*Xgas*), and is therefore often known as the *pneumogastric*. It has thus an extraordinarily wide distribution (vagus=wandering), being in fact the only cerebral nerve which supplies parts beyond the head. It is a mixed nerve, and contains many motor fibres, but its branches—some of which have to do with the regulation of the heart's contraction and with respiration—are better described as *efferent* and *afferent* than as motor and sensory: the meaning of these terms will be explained later on. The ninth and tenth nerves leave the skull close together through the aperture noticed in the exoccipital bone.

The sympathetic nerve (*Sy*) extends forwards from its junction with the first spinal nerve, joins the vagus, and finally ends anteriorly in the Gasserian ganglion.

Microscopic Structure of Nervous Tissue.—Nervous tissue consists of cells provided with processes for the purpose of receiving and conducting impulses. Every such cell or *neuron* consists of (1) a cell-body, containing the nucleus, (2) a long process known as the *axon*, along which impressions from the exterior are brought to the cell or impulses are carried away from it, and (3) other processes, usually short, numerous, and branching, known as *dendrons* or *dendrites*, which convey the impression to other neurons or along which the impulses reach the cell. The axon is often of very great length and forms the basis of a *nerve-fibre*. Examination of a piece of nerve under the microscope shows it to be composed, like striped muscle, of cylindrical fibres, bound together by connective-tissue. The latter is much more abundant than in muscle, and in particular forms a thick sheath round the nerve which must be torn off before the *nerve-fibres* are reached.

Each fibre (Figs. 59 and 60) is a cylindrical cord in which three parts can be distinguished. Running along the axis of the fibre is a delicate protoplasmic strand, the *neuraxis* or *axis-fibre* (*nx*). Around this is a sheath formed of a fatty substance and known as the *medullary sheath* (*m. s*);[1] and, finally, investing the whole fibre is a delicate, structureless membrane, the *neurolemma* (*ne*). At intervals the medullary sheath is absent, and a *node* (*n. R.*) is produced, where the fibre consists simply of the neuraxis covered by the neurolemma. Underlying the neurolemma are found at intervals *nuclei*

[1] The medullary sheath may be absent in certain nerve-fibres (*e g.*, in the sympathetic and olfactory nerves). Such fibres are described as non-medullated nerve-fibres.

muscle itself or to its nerve. You are now in a position to pursue the subject of the control of various parts of the body by the nervous system a little further.

A frog is either decapitated or pithed, *i.e.*, the medulla oblongata is severed and the brain destroyed: there can be thus no question either of sensation or of voluntary action on the frog's part. It is then hung up by a hook or string, so that the legs are allowed to hang freely. If one of the toes is pinched with the forceps, the foot will be drawn up as if to avoid the pinch; or, if some very weak acid be applied to a toe, the foot will again be withdrawn, being raised every time it is touched with the acid with the regularity of a machine. Again, if acid be applied to various parts of the body, the foot of the same side will immediately try to rub off the irritating substance; or if that foot be held down, the other will come into play.

Movements of this kind are called *reflex actions:* the stimulus applied to the skin is transmitted by sensory nerve-fibres to the spinal cord, where it is, as it were, reflected in another form, and passed along motor fibres to one or more muscles, causing them to contract (p. 63).

It must not be concluded from the above that reflex actions are only performed by a decapitated frog. A large number of the movements we ourselves are constantly performing are brought about by reflex action. If a strong light is flashed across the eyes or a finger brought near one of them, the eyelids are instantly closed; if the hand comes in contact with a hot body it is at once withdrawn; if a sudden sound is heard, we start: these are instances of reflex actions, the movements being produced by the agency of the central nervous system without the action of the will, and as the result of sensory impulses reaching it. In some of these instances the reflex action is carried out, not by the spinal cord alone, but by the intervention of the brain also, and, in the first illustration, exclusively by the latter. Many movements of ordinary life which are started by the will, and are therefore voluntary, are often continued reflexly.

Thus we can go on walking without thinking about it, every step being properly taken, the necessary muscles contracting because they receive impulses from the central nervous system, regulated in accordance with sensory impulses received by the central nervous system from the eye or the ear, or due to the contact of the feet themselves with the ground.

As already stated, the spinal nerve-trunks are mixed, *i.e.*, contain both sensory and motor fibres, which, however, cannot be distinguished from one another structur-

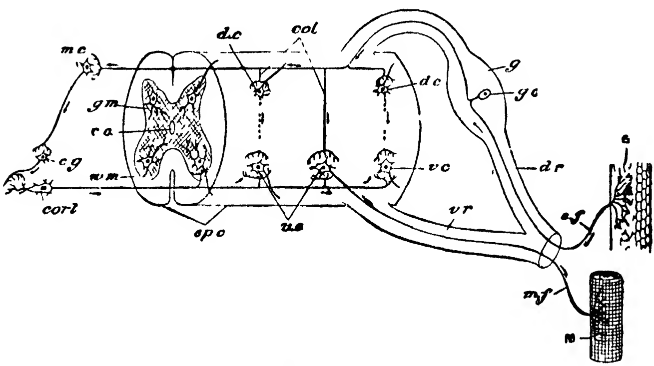

FIG 61 —Diagram illustrating the paths taken by the nervous impulses *c c* central canal; *col* collaterals; *c cort* cell in rind or cortex of the cerebral hemisphere, *c g* smaller cerebral cell, *d c* cells in dorsal horn of grey matter; *d r* dorsal root, *g* ganglion of dorsal root, *g c* cell in ganglion of dorsal root; *g m* grey matter, M muscle. *m c* cell in medulla oblongata, *m f* motor fibre, s skin, *s. f.* sensory fibre; *sp. c* spinal cord; *v c* cells in ventral horn of grey matter, *v r* ventral root, *w. m* white matter. The arrows indicate the direction of the impulses

ally. It has been found by numerous experiments that as the nerve approaches the spinal cord these two sets of fibres separate from one another, the sensory fibres passing into the cord by the dorsal root, the motor by the ventral root. As a consequence of this, if the dorsal root be cut and its proximal or central end—*i.e.*, the end in connection with the cord—stimulated, muscular contraction will follow just as if the stimulus

had been applied to the skin supplied by the nerve in question. If the other cut end—the distal or peripheral end—be stimulated, there is no result. On the other hand, if the ventral root be cut and its distal end stimulated, the muscles supplied by it will contract, while stimulation of the proximal end produces no result.

Very accurate observations have shown that the connection between the motor and sensory fibres is as follows (Fig. 61). A motor fibre (*m. f*) is traceable from the nerve-trunk through the ventral root (*v. r*) into the white matter; and then, its medullary sheath being lost, passes into the ventral horn of the grey matter, its neuraxis being directly continuous with the axis-fibre process of one of the large motor nerve-cells (*v. c*): the remaining processes of these cells simply branch out in the neuroglia. The sensory fibres (*s. f*) are traceable into the dorsal root (*d. r*); in passing through the ganglion of the root (*g*) they are found to be continuous with its simple ("bipolar") nerve-cells (*g. c*), and then pass into the cord. Instead, however, of entering the grey matter at once, they pass forwards as well as backwards for some distance, along the white matter of the cord, giving off numerous branches, or *collaterals* (*col*), which, losing their medullary sheaths, enter the dorsal horn of the grey matter and branch out into a complex series of fine fibres which interlace with the similar arborisations of the nerve-cells in the cord (p. 177).

The path of a nervous impulse known as the *reflex arc* or *chain* will now be obvious. The stimulus applied to the skin (Fig. 61, s) is conducted by a sensory fibre to the nerve-trunk and by the dorsal root to a cell in the ganglion and thence to the spinal cord; it then passes along the white matter of the cord, enters the

grey matter, and is conducted by the collaterals to the nerve-cells of the ventral horn, either directly, or indirectly after passing through the cells of the dorsal horn: from one of the cells of the ventral horn it is conducted by an axon which becomes the neuraxis of a nerve-fibre, which, leaving the cord by a ventral root, passes along the nerve-trunk and finally goes to a muscle (M) as a motor fibre.

It will be noticed that a single stimulus applied to the skin may result in the contraction of numerous muscles—as, *e.g.*, when the application of a drop of acid to the toe causes the lifting of the leg—and that the movements are of such a nature as to withdraw the part stimulated from the irritating substance. Moreover, as shown by the experiment of applying acid to various parts of the body, the movements are varied according to circumstances; if one leg is prevented from rubbing off the irritating substance, the other immediately comes into play. Obviously, then, a simple stimulus reaching the spinal cord may be transmitted to numerous motor cells of the ventral horn, and through these to numerous motor nerves, the particular nerves affected differing according to circumstances (compare Fig. 61). The spinal cord, therefore, is able, in response to a stimulus reaching it by a sensory nerve, to originate motor impulses causing complex muscular movements so adjusted as to serve definite purposes. Without such external stimulus, however, the spinal cord of a brainless frog is quite inactive, and the body of the animal will remain without movement until it dries up or decomposes.

Functions of the Brain.—In the uninjured frog, *i.e.*, the frog with its brain intact, the case is very different. The animal no longer acts like an unintelligent machine, each stimulus producing certain inevitable movements

and no others; but a single stimulus may produce varied movements, the nature and direction of which cannot be predicted. The frog will probably give a series of leaps, but the number and extent of these vary according to circumstances; its movements are *voluntary*, not reflex.

This is explained by the fact that certain nerve-fibres of the cord pass forwards to the brain, and that the nerve-cells in the grey matter of the cord are in communication—owing to the interlacing of their branching processes with those of the collaterals—with similar cells in the grey matter of the brain (Fig. 61, *m c, c.g, c.cort*). In certain of these brain-cells (*c. cort*), voluntary impulses originate and exercise a controlling effect upon the cells of the spinal cord, so that these latter do not constitute, as in the brainless frog, a machine every movement of which can be accurately predicted.

Moreover, it can be shown by experiment that the process of originating voluntary impulses is not performed by the whole brain, but is confined to the cerebral hemispheres. If the hemispheres and optic lobes are removed so as to leave nothing but the bulb and cerebellum, the frog no longer lies in any position in which it may be placed, exhibiting no movements beyond the beating of the heart, as is the case when the whole brain is removed. It sits up in the ordinary attitude, breathes, swallows food placed in the mouth—while making no attempt to feed itself, turns over and sits up if placed on its back, and swims if placed in water. If left alone, however, it remains in the sitting posture till it dies. Hence the bulb and cerebellum are evidently concerned with the *co-ordination* of muscular movements, but have no power of originating impulses. If the optic lobes as well as the medulla oblongata and cerebellum are left, the animal is affected

by light, is able to perform complex balancing movements, and will even croak when stroked in a particular way. There is still, however, no voluntary action; without the application of stimuli, the animal sits motionless until it dies.

To sum up in the language of the illustration with which this chapter was begun, comparing the frog with an engine of human construction:—the grey matter of the brain may be compared with the engineer; much of the work of the engine may go on without him, certain levers, valves etc., acting automatically; but it is only by his controlling intelligence that the whole mechanism is adapted to the circumstances of the moment.

Control over Viscera, Blood-vessels, and Glands.—So far we have considered the nervous system only in its relations to the skin or general surface of the body and to the muscles or organs of movement. The other parts of the body are, however, under nervous control.

It has been mentioned that the heart continues to beat in a frog when the brain has been removed: not only so, but it pulsates with perfect regularity when removed from the body. This is due to the fact that the muscles of the heart, like the cilia of ciliated epithelium, have the power of contracting rhythmically quite independently of the nervous system, although the heart contains nerve-cells which were formerly supposed to serve as a special nervous system for this organ, originating all its motor impulses. It is, however, under the control of the central nervous system. We have seen that it is supplied by a branch of the vagus; when this is stimulated, the heart stops in the dilated state and begins to beat again only after a certain interval. A feeble stimulus to the vagus will not actually stop the heart, but will diminish the rate and the strength of its contractions and consequently the

amount of blood propelled through the body. The vagus is accompanied by a branch of the sympathetic which has an exactly opposite effect, *i.e.*, stimulation of it accelerates the heart's action. In this way, the general blood-supply of the body is regulated by the central nervous system.

The blood-supply of the various parts and organs is regulated by the *vaso-motor nerves*. These are traceable through the sympathetic into the spinal cord by the ventral roots: distally they send branches to the muscular coat of the arteries. Under ordinary circumstances a constant succession of gentle stimuli pass along these from a group of nerve-cells in the medulla oblongata, and, as the result, the arteries are ordinarily in a state of slight contraction. By various circumstances these stimuli may be diminished for any given artery and at the same time stimuli pass down another kind of vaso-motor fibres: the artery will then dilate and the blood-supply of the organ to which it is distributed will be temporarily increased. For instance, the presence of food in the stomach acts, through the central nervous system, upon the cœliac branch of the splanchnic artery, causing a dilatation of its capillaries and promoting an increased secretion of gastric juice. The secretion of other glands is regulated in a similar way. In some cases, however, it has been proved that the nerves of a gland do not act simply by producing dilatation of the capillaries, but have a direct effect upon the gland-cells, causing an increased secretion.

You will thus note that there are nerve-fibres carrying impulses to the central nervous system which have nothing to do with sensation, and fibres carrying impulses from the central nervous system which have nothing to do with motion, but result in increased secretion or in stoppage of motion. It is therefore best

to use the term *afferent* (which includes sensory) for a nerve carrying an impulse to the brain and spinal cord, and *efferent* (including motor) for one carrying an impulse in the other direction.

Functions of the Nervous System: Summary.—To sum up, we have seen that the spinal cord is not only concerned with the conduction of impulses to and from the brain, but is also able to originate well-organised movements in response to an external stimulus. The medulla oblongata originates and regulates the nervous impulses which cause respiratory movements. It also regulates the rate and strength of the beat of the heart (through the vagus and the cardiac branch of the sympathetic), and also, by impulses sent through the vaso-motor nerves, the size of the small arteries. It governs the act of swallowing and the secretion of various digestive and other juices in the body. Along with the cerebellum it brings about the co-ordination of muscular movements. It is thus responsible for all the routine affairs of the body. In addition, it acts as a conductor of all impulses from the cerebral hemispheres and other parts of the brain to the spinal cord and from the spinal cord to the cerebral hemispheres. The cerebral hemispheres are the seat of perceptions, intelligence, and will. The various cerebral and spinal nerves are concerned with the carrying of afferent (sensory) and efferent (motor) impulses of varied character to or from the brain or the spinal cord. The sympathetic nerves chiefly carry impulses which govern the muscular tissue of the viscera and the muscular coat of the small arteries of the various parts of the body. Thus the stomach may be affected through the sympathetic in severe mental distress, which may thus lead to disturbances of digestion; some emotions, such as shame, may lead to blushing, caused by the dilatation of the small blood-vessels of the

skin of the face, and others, such as fright, to pallor, caused by constriction of the same vessels. It must be remembered, however, that the sympathetic nerves receive the impulses which they carry from the central nervous system, and that these impulses do not arise in the sympathetic cord itself.

PRACTICAL DIRECTIONS

I. **The Central Nervous System** (Fig. 7).—Lay bare the brain and spinal cord as directed on p 34, noting the *dura mater* and *pia mater* · the latter is densely pigmented over parts of the brain The specimen on which this operation has already been performed will do, if the dissection has been done carefully.

Observe the origins of the *cerebral* and *spinal nerves*, noting the long *dorsal* and *ventral roots* of the latter (compare Fig. 57) which pass backwards for some distance before making their exit from the neural canal; and also the *ganglia* on the dorsal roots, lying just outside the canal and each hidden by a whitish calcareous body in this region (Fig. 56, C) (The ganglia, however, can be more easily made out at a later stage.) Then sever the nerves very carefully from the brain and spinal cord and remove the whole central nervous system from the neural canal: it is best examined after hardening in formaline or spirit. Lay it in a dissecting-dish, under water, and make out its several parts as follows :—

a. The spinal cord.

1. Note its cylindrical form, the *brachial* and *sciatic swellings*, the *filum terminale*, and the *dorsal* and *ventral fissures*.

2. Examine a transverse section of the spinal cord, prepared as described on p. 145, under the low power of the microscope, and make out the *dorsal* and *ventral fissures*, the *central canal*, and the relations of the *grey* and *white matter* (Figs. 53 and 57). Sketch.

b. The brain (Fig. 54).

Beginning from the posterior end of the brain, where it

Tease out another piece of fresh nerve in chloroform, so as partially to dissolve the medullary sheath, and note the central *neuraxis* Sketch.

Tease out in glycerine a piece of nerve which has been treated with a 1 per cent. solution of osmic acid in water for an hour or two and then well washed in water. The *medullary sheath* will appear nearly black, and the *neurolemma*, the *nuclei* of the sheath, as well as the *nodes*, can be plainly seen. Sketch.

Reflex Action. The experiment described on p. 179 should be seen.

CHAPTER XI

THE FROG (*continued*): THE ORGANS OF SPECIAL SENSE

In the previous chapter you have learnt how the nervous system controls the various functions of the body, and how voluntary action is absolutely dependent upon the connection of the brain, through the spinal cord, with the nerves. Obviously, in order that the power of voluntary action should be of full use to its possessor, some means of communication with the external world is not only desirable but necessary; the frog, in order to adjust its actions to the circumstances in which it from time to time finds itself, must be able to distinguish friends from enemies, suitable from unsuitable food, darkness from light, heat from cold.

The avenues of communication between the animal and its surroundings are, as in ourselves, the *senses of touch, taste, smell, sight,* and *hearing.*

The sense of **touch**, including that of *temperature*, is lodged in the whole extent of the skin, which, as you have already learnt, is abundantly supplied with sensory nerves. Many of the nerves terminate in connection with what are known as *tactile cells*—large flattened cells arranged in groups just below the epidermis and around which the ultimate fibres of the sensory nerves are distributed. Stimuli applied to the skin, either by direct touch or by the heat of the sun, are transmitted to the

tactile cells and thence through the sensory nerves to the brain. Notice that the stimulus is transmitted to the nerve-ends through the epithelial cells of the skin; if the skin be wounded and a stimulus applied directly to the tactile cells or the nerves, the sensation is one, not of touch, but of pain.

The sense of **taste** is lodged in the mucous membrane of the mouth, especially on the tongue and in the neighbourhood of the vomerine teeth, but extending also as far back as the gullet. Certain of the epithelial cells have an elongated form and are arranged in groups known as *taste-buds*, to which the fibres of the ninth and palatine branch of the seventh cerebral nerves, or nerves of taste, are distributed; on the tongue these taste-buds are situated on *papillæ* of the mucous membrane. In this case the stimulus is supplied, not by direct touch or by alteration of temperature, but by the contact of sapid or tasty substances. As before, the stimulus is applied to epithelial cells, and by them transmitted to the nerves and so to the brain, when the sensation of taste becomes manifest. Thus, just as common sensation may be abolished, in any part of the body, in three ways—by destruction of the skin, by cutting the sensory nerve, or by destroying the cerebral hemispheres—so the sense of taste is lost if either the mucous membrane of the mouth is injured or if the glossopharyngeal and palatine nerves are cut, or, again, if the cerebral hemispheres are destroyed.

The sense of **smell** is lodged in the *nasal* or *olfactory sacs*, which are enclosed in the olfactory capsules of the skull and separated from one another by a partition, the *nasal septum*. Each sac has two apertures, the *external nostril*, opening on the surface of the snout, and the *internal nostril*, opening into the mouth (p. 17). The sacs are lined by a delicate mucous membrane, some of

less, transparent jelly, the *vitreous humour*, surrounding which, everywhere but on its external face, is a thin semi-transparent membrane, reddish when perfectly fresh, but becoming grey soon after death; this is the *retina* (*r*). Between the retina and the sclerotic is a vascular membrane called the *choroid* (*chd*), the inner face of which, *i.e.*, that in contact with the retina, is coloured black. It is this layer of black pigment which gives the dark tint to the semi-transparent sclerotic in the entire eye; strictly speaking, it belongs to the retina but actually it adheres to the choroid and appears like the innermost layer of that coat. The retina is readily detachable from the choroid, but at the place where the optic nerve enters (*blind spot*, *b. s*) it becomes continuous with the fibres of the latter, which pass through the sclerotic and choroid. The choroid is made up of connective-tissue and contains numerous vessels as well as pigment-cells.

Lying just internal to the pupil is a nearly globular body, perfectly transparent when fresh, the *crystalline lens* (*l*); it is kept in place by a delicate membrane, the *capsule* of the lens. The iris, which covers the outer face of the lens except where it is perforated by the pupil, is covered on its inner surface with black pigment, and is continuous all round its outer margin with the choroid. Between the iris and the cornea is a space, the *aqueous chamber* of the eye (*aq. c*), which contains a watery fluid, the *aqueous humour*. The main cavity of the eyeball, containing the *vitreous humour*, is called the *vitreous chamber*.

The actual relations of these parts in the entire eye are best grasped in a vertical section, such as is represented in Fig. 63, B. The main part of the eyeball forms a chamber, enclosed by the sclerotic, darkened internally by the choroid and lined by the retina. Into the outer

side of this dark chamber is let a transparent window, the cornea; behind which, and separated from it by a space containing the aqueous humour, is a vertical curtain, the iris, perforated by an aperture, the pupil. Behind the iris and in close contact with it is the lens, and filling the whole of the dark chamber between the lens and iris and the retina is the vitreous humour.

The whole eye thus has the structure of a camera obscura. The cornea, aqueous humour, lens, and vitreous humour are a series of lenses, so arranged that the rays of light from an external object are refracted and brought to a focus on the retina, where they form a greatly diminished and inverted image of the object. The iris is provided with muscles, by means of which the pupil can be enlarged or diminished, it therefore acts as a diaphragm and regulates the amount of light entering the eye. Attached to the capsule of the lens are delicate muscles, by means of which the lens can be shifted to some extent towards the cornea; in this way the focus of the entire apparatus can be altered according to whether the object viewed is nearer or farther from the eye. This arrangement for accommodation is, however, much less highly developed in the frog than in man and the higher animals, in which the relatively smaller lens is flatter and distinctly biconvex in form and is allowed to become more convex anteriorly, through the contraction of the ciliary muscle (Fig. 172). Thus the various parts of this complicated organ are so adjusted as to bring the images of external objects to an accurate focus on the back part of the interior of the eyeball, *i.e.*, on the retina.

A vertical section of the retina (Fig. 64) reveals a very complex structure. On its inner face, *i.e.*, the surface in contact with the vitreous humour, is a layer of nerve-fibres (*n. f*), formed by the ramifications of the

skull (Fig. 12), and consisting of a kind of bag of very peculiar and complicated form (Fig. 65). It is made up, in the first place, of two somewhat ovoid sacs separated by a constriction: the dorsal one is called the *utriculus* (*ut*), the ventral the *sacculus* (*s*), and from the latter a small process, the *cochlea* (*cc*), projects backwards. With the

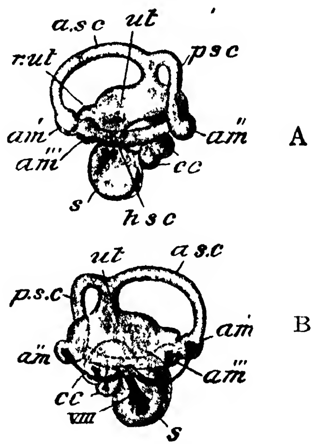

FIG 65 —The membranous labyrinth of the Frog's ear A, outer, and B, inner view (× 6)
am′, *am″*, *am‴*, ampullæ of the semicircular canals, *a s c* anterior semicircular canal, *cc.* cochlea; *h s c.* horizontal (external) semicircular canal, *p. sc.* posterior semicircular canal, *r ut* recess of the utriculus, *s.* sacculus; *ut.* utriculus; *VIII* branches of auditory nerve. (After Howes)

utriculus are connected three tubes, called, from their form, the *semicircular canals*, each of which opens into the utriculus at either end. One of them, the anterior canal (*a.s.c*), is directed forwards; another, the posterior canal (*p.s.c*), backwards; both these are vertical in position and are united to one another at their adjacent ends. The third, the external canal (*h.s.c*),

is directed outwards and has a horizontal position. Each canal has one end dilated into a bulb-like swelling or *ampulla* (*am*); those of the anterior and external canals are at their anterior ends, while that of the posterior canal is at its posterior end.

The whole of this apparatus is filled with a fluid, the *endolymph*, in which are contained calcareous particles, the *otoliths* or ear-stones. It is made of connective-

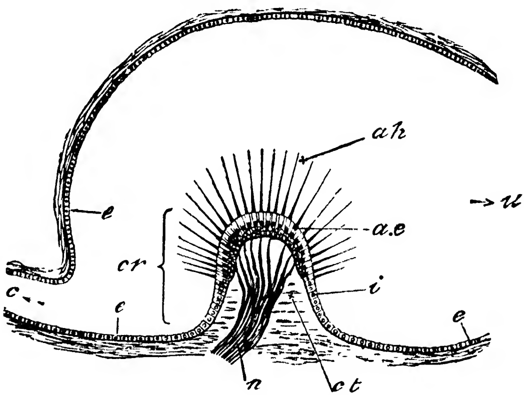

Fig 66—Longitudinal section through an ampulla.
a e auditory epithelium, *a. h* auditory hairs; *c* part of semicircular canal; *c r* acoustic spot and ridge, *c. t.* connective-tissue, *e.* epithelium, *n* nerve; *u.* junction with utriculus (From Foster and Shore's *Physiology*.)

tissue and lined with epithelium, the cells of which are cubical for the most part; but in certain places the wall is thickened, forming what are called *acoustic spots*, of which there is one to each ampulla, situated on a ridge (Fig. 66), while others occur in the utriculus and sacculus. On these acoustic spots the epithelial cells are greatly elongated, and produced at the surface into delicate processes called auditory hairs: to these cells the fibres of the auditory nerve are distributed.

The membranous labyrinth does not fit tightly into the cavity of the auditory capsule in which it is contained, a space being left between it and the surrounding bone and cartilage (Fig. 12). This space is filled by loose connective-tissue and a fluid called *perilymph*, by which the membranous labyrinth is surrounded and protected from shocks. As you learnt in studying the skull, the outer wall of the auditory capsule is perforated by a small aperture, the *fenestra ovalis* (Fig. 12, *fen. ov*), in which is fixed the *stapedial plate* (*stp*), a small nodule of cartilage connected with a bony rod or *columella* (*col*), the cartilaginous hammer-shaped outer end of which, or *extra-columella*, is fixed to the inner side of the *tympanic membrane* (*tymp. memb*). The columella lies in the *tympanic cavity* (*tymp. cav*), which is bounded externally by the tympanic membrane, internally by the auditory capsule, and at the sides chiefly by muscles and connective-tissue; while below it communicates with the pharynx by the *Eustachian tube* (*eus. t*).

When sound-waves impinge on the tympanic membrane, the vibrations to which they give rise are transmitted by the columella to the stapedial plate, and so to the perilymph. Thence they are communicated to the endolymph and act as stimuli to the auditory cells of the acoustic spots, and the impulses, being carried to the brain by the auditory nerve, give rise to the sensation of sound. Whether or not all the acoustic spots are truly auditory in function is not known: it seems that the semicircular canals are really concerned with the sense of direction and velocity and with the maintenance of equilibrium.

The sense of sound can be destroyed by injury to the membranous labyrinth, by cutting the auditory nerve, by destroying the brain, or—to a great extent at least—by injury to the tympanic membrane or columella.

Notice that the general plan of all the sensory organs, those of the skin, eye, and ear, is the same. They consist of certain peculiarly modified epithelial cells, specially sensitive to impulses of particular kinds, and in communication, by means of an afferent nerve, with nerve-cells of the brain. The three things—sensory cell, afferent nerve, and brain—form a chain every link of which is necessary for the performance of the sensory function, so that the particular sense in question may be destroyed, not only by destruction of the sense-organs in the strict sense, but also by section of the afferent nerve or by destruction of the brain.

General Physiology—Summary.—Before going on to the next chapter it will be as well to take a final glance at the physiological processes of the frog as a whole (compare Fig. 27). The enteric canal is the factory in which the raw material of the food is worked up into a form in which it can be used by the various parts of the body. The circulatory organs are the communicating system by which the prepared food is taken to all parts; and they also form a drainage system by which waste matters are collected from all parts and finally ejected by the three main sewers, the skin, lungs, and kidneys. The skin and lungs, besides getting rid of waste matters, serve for the supply of oxygen—a necessary form of gaseous food. The central nervous system forms a sort of headquarters' staff by which the entire body is controlled, the means of communication being the nerves, and the muscles the executive by which the orders from headquarters are executed. And finally the sense-organs may be looked upon as the various branches of an intelligence department by which the headquarters are informed of what is going on outside.

PRACTICAL DIRECTIONS

The Organs of Special Sense

I. *Olfactory organ.* Notice again the *external* and *internal nostrils.* Then remove the skin covering the snout, dissect off the nasal bones, and open up the *olfactory sacs.* Note, using a lens, the pigmented *olfactory epithelium* lining these, and make out the *olfactory nerves* and *nasal septum.* Compare with a transverse section through the sacs. Sketch.

II. *Eye.*

a. Notice again the *eyelids, iris,* and *pupil.* Then remove the skin covering the head so as to expose the nearly globular *eyeballs,* lying in the *orbits.* Examine with a lens.

In the antero-ventral region of the orbit make out the *Harderian gland,* and the *eye-muscles* passing from the walls of the orbit to the eyeball. The four *recti* and two *oblique muscles* can be more easily seen on a larger animal, and directions will be given for their examination in Part II (see Fig. 135); but if you make a dissection of them in the frog, you should note at the same time the *levator* and *retractor bulbi,* the latter underlying the eyeball, and the former situated internally to the recti muscles.

b Remove the eyeball from a freshly-killed specimen, noticing as you do so the *optic nerve,* which is surrounded by the recti and retractor bulbi muscles: dissect away these muscles and note the cartilaginous *sclerotic,* the *cornea, iris, pupil,* and the cut end of the optic nerve

c. Divide the eyeball into an inner and an outer hemisphere by a rapid cut with scalpel or scissors taken vertically, midway between the cornea and the optic nerve, through the *vitreous chamber.* Place them both in a watch-glass or small dissecting-dish, under water, and examine with a lens (compare Fig. 63). In the inner hemisphere note the *vitreous humour, retina,* pigmented *choroid,* and *blind spot* or entrance of the optic nerve; and in the outer hemisphere, the *crystalline lens* and the margin of the retina, or *ora serrata.* Sketch. Remove the lens, and notice the *iris*—continuous with the choroid, the *pupil,* and the *aqueous chamber.*

d. Examine sections through the wall of the inner hemisphere of the eyeball, prepared as directed on p. 145, first

under the low and then under the high power of the microscope. Note :—

1. The cartilaginous *sclerotic*.

2. The *choroid*, enclosing pigment-cells and blood-vessels.

3. The *retina* (Fig. 64), composed of a number of layers : notice the *pigment epithelium*, the *rod-* and *cone-layer* and the various other layers of the retina, the innermost of which is composed of nerve-fibres continuous with the optic nerve.

Sketch.

The anatomy of the eye can be more easily made out by dissecting that of an ox or sheep, which is essentially similar to that of the frog, and directions for the examination of which will be given in Part II.

III. *Auditory organ.*

Notice again the *tympanic membrane* and *tympanic ring*, and then carefully cut away the former so as to expose the *tympanic cavity*. Observe the *Eustachian tube*, the *fenestra ovalis*, and the relations of the *stapedial plate*, *columella*, and *extra-columella* (Fig. 12).

The *essential* part of the auditory organ (*membranous labyrinth*) is very small in the frog, and can be more satisfactorily studied in a good-sized fish (*e.g.*, dogfish or cod). Directions for the preparation of the membranous labyrinth of the former will be given at a later stage (p. 448), but if you have sufficient time and patience to dissect it out in the frog, proceed as follows :—

Place the head of a large frog in nitric acid (about 10 per cent.) until the bone is dissolved. Wash well in water so as to remove the acid, and dissect away the muscle, etc., from the auditory capsule until the latter is thoroughly exposed. Then with a sharp scalpel slice away the roof of the capsule until the cavity it contains is seen. Proceed now with great caution, removing the cartilage and decalcified bone, bit by bit, until the cavity is sufficiently enlarged to bring the membranous labyrinth into view (compare Figs. 12 and 65). Observe the *utriculus*, *sacculus*, *otoliths*, and the three *semicircular canals* with their *ampullæ*. Sketch.

eggs, are correspondingly reduced in size, and all the other organs are squeezed out of place.

Fertilisation.—The eggs are now laid, and immediately the spawn is passed from the oviducts of the female into the water, the male sheds over them a quantity of spermatic substance (p. 10). The sperms, swimming actively through the water, enter the spheres of jelly and come into contact with the eggs. A single sperm then penetrates the egg-membrane of an ovum, loses its tail, and its head coming into contact with the nucleus of the egg, fuses or *conjugates* with it, so that a single nucleus is formed by the union of the egg-nucleus with the sperm-nucleus. The details of this process, as also of the development of the sperms and the maturation of the ovum, will be found in Part II, Chapter X, but can be left out of consideration for the present. We may speak of conjugating cells in general as *gametes*, the sperm in this case being the male gamete, and the ovum the female gamete, the body formed by the fusion of two gametes being known as a *zygote*.

This process is known as *fertilisation* or *impregnation*. Without it, as we have seen, the egg is incapable of development; after it has taken place, the egg—or more strictly, the *oosperm*, since it is now an ovum *plus* a sperm—is potentially a young frog, since, if left undisturbed in water, it will in course of time give rise to a tadpole, which in its turn will change into a frog.

It must be remembered in the first place that the fertilised egg is a single cell, comparable with a blood-corpuscle or an epithelial cell. It is, however, peculiar in two respects; first in having its nucleus derived in part from a sperm, so as to contain matter from both the male and the female parent; and secondly in having its protoplasm distended with yolk-granules to such an

extent that, instead of being a minute body visible only under the microscope, it is easily visible to the naked eye. The yolk is not equally distributed: on one hemisphere it is less abundant than elsewhere, and it is this more protoplasmic hemisphere which is superficially blackened by a layer of pigment, and which always floats upwards in the water when the egg is laid.

Segmentation of the Oosperm.—Almost directly after being laid and fertilised the egg undergoes a remarkable change. A furrow appears all around it, as if made with a blunt instrument, and deepening gradually, at last divides the oosperm into two hemispheres in contact with one another by their flat faces (Fig. 69, A). The examination of sections shows that this process is preceded by the division of the nucleus into two; its final result is the division of the originally one-celled egg into two cells. Now if you refer to Chapter VIII, you will be reminded of the fact that the epithelial cells of the skin multiply by a similar process of *simple fission*, or division into two; the nucleus in each case dividing first, and afterwards the protoplasm.

The furrow which effects this division of the oosperm passes through both black and white poles, so that each of the two cells formed is half black and half white. Soon a second furrow is formed at right angles to the first, being, like it, meridional, *i.e.*, passing through the poles (Fig. 69, B). It divides what we must now call the *embryo* into four cells, each half black and half white. A third furrow is then formed, passing round the equator, but nearer the black than the white pole (C). It therefore divides the embryo into eight cells, four upper black and four lower white, the latter being obviously the larger.

This process of division or *segmentation of the oosperm* continues, the black cells dividing more rapidly than the

layer, Fig. 70, *mes*[1], *som*), the other with the endoderm (*visceral layer*, *mes*[2], *spl*). The space between them is the *cœlome* (*c*, *coel*). The dorsal part of the mesoderm on either side of the medullary cord and notochord becomes divided transversely, and gives rise to muscle-segments or *myomeres* (Figs. 69, L, and 70).

The embryo soon begins to elongate in a definite direction (Fig. 69, J): its dorsal surface, still marked by the medullary groove, which now soon becomes closed, is slightly concave, its ventral surface very convex. The blastopore closes up, the yolk-plug becoming entirely covered by ectoderm; but for a short time the medullary canal and enteron still communicate by the *neurenteric canal* (K, *n.e.c*). This soon disappears, and at the hinder end of the embryo a conical outgrowth forms the rudiment of the tail (*t*). The opposite end is rounded, and on its ventral surface appears a little half-moon-shaped groove, the rudiment of the sucker by which the tadpole attaches itself to weeds (J and L, *sk*); this afterwards becomes subdivided into two (Fig. 71, C). Just above the sucker a depression—the mouth-pit or *stomodæum* (L, *stdm*)—makes its appearance, and is the first indication of the mouth. A similar depression below the tail—the *proctodæum* (K and L, *pcdm*)—marks the anus: both at first are mere blind pouches and have no communication with the enteric cavity. The head-region is further marked by two pairs of vertical ridges separated by depressions: the ridges are the *branchial* or *gill arches* (J, *br. a*), and the depressions the *branchial clefts*.

Further elongation takes place (Fig. 69, L), the head becomes distinctly marked off, the tail extends considerably beyond the anus, a thickening appears which marks the position of the eye (*e*), and a depression that of the ear (just above *br*[2] in the figure); and from each

branchial arch arises a little tuft, the rudiment of one of the *external gills* (*br*[1], *br*[2]). In this condition the tadpole is hatched: it is still unable to feed, the stomodæum not yet being in communication with the enteric cavity; it is nourished therefore entirely by the yolk with which a large portion of the body is still filled.

Up to the stage shown in Fig. 69, I, the cells of which the tadpole is composed, although distinguishable into ectoderm, endoderm, and mesoderm, are all more or less similar: there are no muscles, no cartilages, bones, or connective-tissue. But shortly after the stage referred to, the permanent tissues begin to be formed. the outer ectoderm cells take on the form of epidermis, the endoderm cells become the epithelium of the enteric canal, and from offshoots of the latter—all of course lined by endoderm—are formed the lungs, the liver, the pancreas, and the urinary bladder.

The mesoderm undergoes much more extensive changes, giving rise to the connective-tissue, cartilage, bone (after the metamorphosis of the tadpole larva is completed) and muscle, as well as to other parts—*i.e.*, to by far the greater portion of the permanent tissues. In certain places the embryonic mesoderm cells, hitherto in close contact, separate from one another and become branched, while between them appears intercellular substance with fibres crossing one another in various directions: in this way the connective-tissue of the adult body is produced.

The various parts of the skeleton first arise by the conversion of portions of the mesoderm into cartilage. The cells retreat from one another and between them a clear substance, the matrix, makes its appearance. For a considerable time almost the whole skeleton consists of cartilage, but after metamorphosis much of this tissue is replaced by bone developed from a layer of cells on

the inner surface of the perichondrium. The bones thus formed in connection with cartilage are *replacing bones: investing bones* arise in connective-tissue which has no direct relation to the cartilage (compare p 45).

In the place where the voluntary muscles are to appear the mesoderm cells elongate, their nuclei multiply by fission, and their protoplasm gradually becomes converted into the striated substance so characteristic of the adult muscular tissue.

These examples will suffice to illustrate the fact, which further study would show to be true, that all the permanent tissues are either—like epithelium—formed entirely of actual cells, or are—like connective-tissue and striped muscle—derived from cells. The entire embryo in its earliest condition—the oosperm stage—is a single cell, which multiplies repeatedly by simple fission, forming a group of cells: and these, by assuming various forms and undergoing various changes, give rise to all the complex tissues—differing from one another both structurally and functionally—of the adult animal. So that every cell, fibre, or what not in the frog is a linear descendant, through repeated fission, of the oosperm; and the oosperm itself is the product of the fusion of two cells, one—the ovum—derived from the female, the other—the sperm—from the male parent. Thus in passing from the oosperm to the adult animal there is a gradual *structural* or *morphological differentiation* accompanied by a *differentiation of function* or *division of physiological labour.*

The expression "division of physiological labour" was invented by the great French physiologist, Henri Milne-Edwards, to express the fact that a sort of rough correspondence exists between lowly and highly organised animals and plants on the one hand, and lowly and highly organised human societies on the other. In

primitive communities there is little or no division of labour: every man is his own butcher, baker, soldier, doctor, etc., there is no distinction between "classes" and "masses," and each individual is to a great extent independent of all the rest; whereas in complex civilised communities society is differentiated into politicians, soldiers, professional men, mechanics, labourers, and so on, each class being to a great extent dependent on every other.

Development of other Organs—Structure and Metamorphosis of the Tadpole—Metamorphosis.—A sketch of the further development of the tadpole and of its metamorphosis has already been given (pp. 10, 12, Fig. 2), but it is now necessary to add a few details to those already mentioned.

A third pair of branchial arches appear behind the two already noticed, and on each a third external gill. The first two pairs increase greatly in size and all the gills become branched (Fig. 71, A). The four branchial clefts communicate with the pharynx, and a current of water enters the mouth and passes out by these clefts, thus providing the gills with a constant supply of aërated water for purposes of respiration, as in a fish. A thin median fold of the skin, the *tail-fin* (Fig. 2), arises all round the tail, both above and below, and the tail now forms a powerful swimming organ. The stomodæum and, at a still earlier period, the proctodæum (p. 215) open into the enteric cavity (Fig. 71, B—E), so that there is now a complete enteric canal: it grows much faster than the body generally, and becomes coiled like a watch-spring (D, E). The mouth is very small, and is bounded by lips beset with little horny projections or papillæ and provided with a pair of horny jaws (C—E), with which the tadpole now browses upon the

time the metamorphosing tadpole is nourished largely by its own tail.

The mouth widens, the horny jaws and papillæ disappear, and teeth are formed. The suckers vanish, and the intestine not only begins to grow less rapidly than the body, but even becomes reduced in length and loses its spiral arrangement, while vegetable is exchanged for animal diet. The dark colour of the tadpole gradually gives place to the bright hues of the frog. The little tailed frog can now leave the water and hop about on land: its tail is soon absorbed, and the metamorphosis is complete (Fig. 2, 1—8).

It will be noticed that in the course of development a *substitution* or *replacement* of *organs* occurs. Thus, for instance, the notochord is replaced by a vertebral column, the gills by lungs, and the horny jaws by teeth.

Fate of the Germinal Layers.—In concluding this chapter we may enumerate in rather more detail the chief parts and organs which are derived from each of the three embryonic tissues respectively. From the *ectoderm* are formed—the epidermis and the cutaneous glands; the whole of the nervous system, central and peripheral, and the essential parts of the sensory organs, as well as the crystalline lens of the eye; and also the epithelium lining the mouth (stomodæum) and outer part of the cloaca (proctodæum). The *endoderm* gives rise to the epithelium lining the enteric canal and its various offshoots, including the lungs, urinary bladder, gastric glands, bile and pancreatic ducts, as well as the glandular cells of the liver and pancreas; and to the notochord. From the *mesoderm* are developed the various parts which are situated between the ectoderm and endoderm with the exception of the notochord, *viz.*, the connective-tissue, cartilage, bone, striped and unstriped muscles, circulatory organs, and peritoneum, as

well as the urinary and reproductive organs and the accessory parts of the sensory organs.

Further details about the development of various organs will be found in Part II, Chapter XIII, which should be consulted after other vertebrate types have been studied.

PRACTICAL DIRECTIONS

Organs of Reproduction.

Open a frog in the usual way: cut through the gullet, rectum, and mesentery, and remove all the digestive organs. In the female, take especial care not to injure the roots of the lungs in severing the gullet. One of the specimens you have already dissected and kept in the preservative fluid should still contain the urinogenital organs intact in the case of the male: in the female, the ovaries and greater part of the oviducts will have been removed, but the relations of the two ends of each oviduct can still be made out.

Examine the reproductive organs, which will now be freely exposed, under water—or in the case of the female, in 1 per cent. salt solution.

I. *Male Organs*. (Figs 8 and 25.)

1. Notice again the *spermaries* or *testes*, lying on the ventral surface of the corresponding kidney, and connected with it by a fold of peritoneum, in which note the *efferent ducts* by lifting the testis off from the kidney; the branched *fat-body*; and the *ureter* (*urinogenital duct*). Sketch after examining the cloaca (see next page).

2. Tease up a bit of the spermary of a recently-killed frog in salt-solution, and notice the form and movements of the *sperms* (Fig. 67, B). Sketch.

3. Examine under the microscope a transverse section of the spermary, prepared as directed on p. 145, and note (Fig. 67, A) the numerous *seminal tubes* or *crypts* which open into it. Under the high power, observe the epithelial cells (*germinal epithelium*) lining the tubes, and their subdivision into smaller cells, which eventually give rise to the sperms, the tails of which project freely into the cavities of the tubes. Sketch.

II. *Female Organs.*

1. Notice again—(*a*) the *ovaries*, varying in size and appearance according to the time of year, and each suspended by a fold of peritoneum: they are studded all over with *ovarian follicles*, each of which contains an *egg* or *ovum*, pigmented when ripe; and (*b*) the *oviducts* (Fig 5). Trace the convoluted and glandular middle portion of the oviduct forwards, and make out the anterior thin-walled portion, running parallel to the gullet and opening into the cœlome by a small aperture near the base of the lung; then trace the middle portion backwards, and notice the thin-walled, dilated, posterior portion, which opens into the cloaca Sketch after examining the cloaca (see below).

If a female frog is examined in the spring, just before the eggs are laid, the ovaries will be seen to be reduced in size, and the posterior portion of the oviduct filled with eggs, each surrounded with a gelatinous coat secreted by the middle portion

2. Examine under the microscope a section of the ovary, prepared as directed on p 145, first with the low, and then with the high power (Fig. 68). Note the epithelial cells (including the *germinal epithelium*) forming the walls of the ovary, and the *ovarian follicles* in different stages of development. Each contains an *ovum*, surrounded by *follicle-cells* In the ova, note the *protoplasm* and its contained *yolk-granules*, the *nucleus*, and the *nucleoli*. Sketch.

Cloaca.

Carefully cut through the pelvic symphysis in the middle line with a scalpel and press apart the two innominate bones, so as to expose the ventral surface of the cloaca. Inflate from the vent, and note that the large intestine is continuous with the cloaca and that the urinary bladder opens into it on the ventral side.

The entire urinogenital apparatus, together with the cloaca, may now be removed from the body, first cutting through the skin round the vent. Pin down under water, insert the small scissors into the vent, and slit open the cloaca very slightly to one side of the middle line, so as not to injure the connection between it and the bladder. Notice the openings into the bladder and large intestine respectively, and also:—

In the male, the apertures of the ureters (urinogenital ducts), situated on two small papillæ, lying close to one

another on the dorsal side of the cloaca: insert a bristle into the ureter. Sketch.

In the female, the two small apertures of the ureters, and, just in front of these, the two large apertures of the oviducts, all situated on the dorsal wall of the cloaca. Insert bristles into the ureter and oviduct. Sketch.

Impregnation and Development.

In the early spring (end of February or beginning of March), look about in ponds and ditches for frogs which have taken to the water for the purpose of laying eggs. This process can be watched more conveniently by catching a few frogs, male and female, and putting them in a large vessel of water or aquarium. If you have been unsuccessful in procuring frogs or frogs' spawn, toads will do equally well: their eggs are laid a few weeks later, and are arranged, each surrounded by its gelatinous envelope, not in clumps, like those of the frog, but in a string, like the beads on a necklace.

For purposes of observation, the spawn is best kept in a glass vessel, together with some water-weeds. Put only a small quantity of spawn in one vessel; if the water begins to get foul, change it at once. Examine the eggs every day with a magnifying-glass—or better, a low power binocular microscope—as development proceeds, and keep some of the tadpoles alive until metamorphosis takes place in June.

If you wish to see some of the stages in the development of the frog during other times of the year, you must obtain some preserved eggs and embryos, and, if possible, you should also examine the series of wax models, made on an enlarged scale, which are to be seen in most zoological museums.

The following are some of the more important things to be noticed. (Sketch a series of stages):—

Before hatching.

I. The unsegmented oosperm, black above, and white below.

II. Early stages in segmentation, during which the individual cells can be made out by means of a lens. (Fig. 69, A—F.)

III. Later stages in segmentation, during which the individual cells cannot be distinguished without the aid of a microscope. Note the gradual enclosure of the white by the black hemisphere, until only a small rounded *yolk-plug*

is left, filling in an aperture—the *blastopore*—in the black layer or *ectoderm*, as it is now called. The yolk-plug is continuous with a mass of *yolk-cells*, enclosed by the ectoderm, from which the *endoderm* and *mesoderm* are developed. (Fig. 69, G—I.)

IV. The gradual flattening and elongation of the embryo, and the position of the blastopore at the posterior end of the dorsal region; the formation of the *medullary folds* and *groove* along the dorsal side, and the closure of the blastopore. (Fig. 69, H—J.)

V. The closure of the medullary groove, the formation of the *head* with its *suckers* and of the *tail* with its *tail-fin*, as well as the appearance of the *eyes*, *ear-sacs*, *branchial arches*, *external gills*, and the involutions for the *mouth* and *anus*, which, however, do not open until after the tadpole is hatched. (Fig. 69, K—L.)

After hatching.

VI. The appearance of the *horny jaws* and *papillæ*, and the further development of the head, external gills, and tail. (Fig. 2, 1—2, and Fig. 71, A, B.)

VII. The formation of the *operculum*, the closure of the right opercular aperture, and the disappearance of the external gills. The bud-like rudiments of the *hind-limbs*, and their further development. The fore-limbs remain for a long time hidden beneath the operculum. (Fig. 2, 3—4, and Fig. 71, C—E.)

Metamorphosis.

VIII. The gradual change in the form and colour of the head and body; the widening of the mouth and loss of the horny jaws and suckers; the appearance of the fore-limbs from beneath the operculum, and the shrinking of the tail. (Fig. 2, 5—8.)

Dissection of tadpole.

Pin down a full-sized tadpole under water in a small dissecting-dish, with the ventral surface uppermost, inserting small pins through the tail only. Carefully dissect off the ventral body walls, and note the coiled *intestine*, the *heart*, the *internal gills*, &c. (Fig. 71, D, D[1], E.) Sketch.

It is rather a difficult task, and requires much time, to prepare sections of the early stages of the frog-embryo in order to make out the formation of the ectoderm, endoderm, and mesoderm, the relations of the segmentation-cavity and enteron, and the development of the central nervous system

and notochord (Figs. 69, I, K, and 70); and directions for the practical study of development are given in Part II, Chapter XIII. But if you wish to make the attempt at this stage, proceed as follows :—

Take a few eggs every day from the time they are laid until the tadpoles are hatched: place these on a tile or piece of glass, and with a pair of needles dissect off the gelatinous covering. Then carefully transfer the segmenting eggs or embryos into corrosive sublimate for a quarter to half an hour, and after washing in running water, put them into weak and then strong alcohol; stain, imbed, and cut sections as directed on p. 145.

CHAPTER XIII

THE FROG (*continued*) : MEANING OF THE TERM SPECIES—THE PRINCIPLES OF CLASSIFICATION—EVOLUTION—RECAPITULATION THEORY—GENERAL CHARACTERS AND CLASSIFICATION OF THE AMPHIBIA

Meaning of the term Species.—The frog which you have been studying is only one of those commonly found in India. Many other kinds are also found in different parts of India, but the frog commonly met with in England (*R. temporaria*) and another common on the European continent (*R. esculenta*), references to which have occasionally been made in figures in this book, are not found in India. Various other frogs, differing in certain minor respects from these, are found in different parts of the world. This fact is expressed in the language of systematic zoology by saying that there are various **species** of frogs, belonging to the same **genus**, which are distinguished from one another by certain definite characteristics as regards form, structure, and colour.

According to the system of *binomial nomenclature* introduced by Linnæus, each kind of animal receives two names—one, the *generic name*, common to all the species of the genus ; the other the *specific name*, peculiar to the species in question. Both generic and specific names are Latin in form, and are commonly Latin or Greek in origin, although frequently modern names of

persons or places with Latinised terminations are employed. In giving the name of an animal, the generic name is always placed first, the specific name following it, and being written as a rule with a small letter. Thus the common Indian frog is called *Rana tigrina*, the common English frog is named *Rana temporaria*, and the European form, often spoken of as the edible frog, *Rana esculenta*. Another widely distributed Indian frog is *Rana cyanophlyctis*.

You will probably have noticed certain differences in colour and markings in the different individual frogs you have examined, and it is matter of common observation that no two individuals of a species are exactly alike. In the case of human beings and many of the more familiar animals this is very apparent to everyone: in other cases a more careful examination of the individuals is necessary in order to tell them apart; thus, for instance, the individuals in a flock of sheep appear all alike to the casual observer, but the shepherd can easily distinguish them from one another. These differences we designate *individual variations*, and it is often difficult to decide whether two kinds of animals should be considered as distinct species, or as varieties of a single species, and no universal rule can be given for determining this point. Among the higher animals, mutual fertility is a fair practical test, the *varieties* of a species (*e.g.*, common pigeon, fowl, dog, horse) usually breeding freely with one another and producing fertile offspring, while distinct *species* usually do not breed together, or else produce infertile hybrids or *mules*. Compare for instance the fertile mongrels produced by the union of the various breeds of domestic dog with the infertile mule produced by the union of the horse and ass. But this rule is not without exception, and in the case of wild animals is, more often than not, impossible of applica-

a brown or olive colour with dark spots and with small tubercles or warts, by the fingers being slender, pointed, first finger not extending beyond the second, and by the pointed toes being webbed to the tips, the fourth toe being not much longer than the third or the fifth. On the other hand, these two frogs agree with one another and with all the other species of the genus *Rana*, in having teeth on the upper jaw, and in not having the transverse processes of the sacral vertebra dilated.

FIG. 73.—*Triton cristatus*. 1, Female, 2, Male in nuptial dress. (From *Cambridge Natural History*)

Comparing all these frogs with our Indian toads (Fig. 72), of which there are several species, we find that in them the skin is comparatively dry and covered with glandular warts, the hind-limbs are proportionally shorter, there are no teeth, and the transverse processes of the sacral vertebra are more or less dilated. These differences are so great as not only to necessitate placing the toads in another genus (*Bufo*), but also to relegate the frogs just mentioned to one **family**—the *Ranidæ* (including

many genera), and the toads to another—the *Bufonidæ*. All frogs and toads, however, agree with one another in having no tail in the adult, while the trunk is relatively short and broad, and the hind-limbs are longer than the fore-limbs. They therefore differ fundamentally from such animals as the common English newts (Fig 73) and the salamanders, which retain the tail throughout life, and in which the fore- and hind-limbs are of approximately equal size. The differences here are obviously

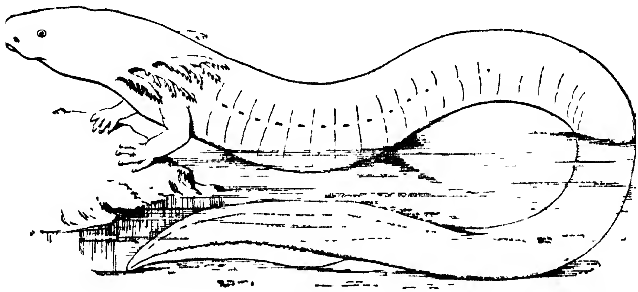

FIG. 74. *Siren lacertina* (× ⅓) (From *Cambridge Natural History*.)

far greater than those between the families mentioned above, and are emphasised by placing the frogs and toads in the **order** *Anura*, the newts and salamanders in the order *Urodela*. The newts and salamanders lose both gills and gill-slits completely in the adult; but in certain other Urodela (such as the blind, cave-dwelling *Proteus* and *Siren* (Fig. 74) either gills are retained throughout life or gill-slits remain as a permanent record of their presence in the larva. In some of these tailed Amphibians the limbs are well-developed, in others they are quite small, or the hind-limbs are even absent as in *Siren*. There is still a third order of Amphibians, known as the *Gymnophiona* which are quite snake-like in ap-

pearance, owing to the narrow and elongated form of the body and the entire absence of limbs.

The *Urodela, Anura, and Gymnophiona,* although differing from one another in many important respects, agree, *e g.*, in possessing gills during part or the whole of their existence, and in nearly always possessing lungs. They usually pass through a metamorphosis, the young being hatched in the form of gilled larvæ; their skin is soft and glandular, and the toes are in nearly all cases without claws. These and numerous other structural characters separate them from reptiles, in which gills are never developed, and the young do not pass through a metamorphosis, while the skin is provided with scales and the toes have claws. The differences here are considerably more important than those between the orders referred to above, and are expressed by placing the latter in the **class** *Amphibia,* while reptiles constitute the class *Reptilia.* In the same way the fishes, which possess fins and gills, form the class *Pisces,* the feathered birds the class *Aves,* and the hairy animals which suckle their young the class *Mammalia.*

Mammals, Birds, Reptiles, Amphibians, and Fishes all agree with one another in the possession of red blood and an internal skeleton, an important part of which in the embryo is the notochord (p. 214)—which is nearly always replaced in the adult by a backbone or vertebral column—and in never having more than two pairs of limbs. They thus differ in some of the most fundamental features of their organisation from such animals as Crabs, Insects, Scorpions, and Centipedes, which have colourless blood, a jointed external skeleton, and numerous limbs. These differences—far greater than those between classes—are expressed by placing the back-boned animals in the **phylum or sub-kingdom** *Vertebrata,* the many-legged, armoured forms in the

phylum *Arthropoda*. Similarly, soft-bodied animals with shells, such as mussels and snails, form the phylum *Mollusca*; various worms, such as the earthworm, the phylum *Annulata*; polypes and jelly-fishes the phylum *Cœlenterata*; the simplest animals, mostly minute, such as *Amœba*, the phylum *Protozoa*. Finally, the various phyla recognised by zoologists together constitute the **kingdom** *Animalia*.

Thus the animal kingdom is divided into phyla, the phyla into classes, the classes into orders, the orders into families, the families into genera, and the genera into species; while the species themselves are assemblages of individual animals agreeing with one another in certain definite characteristics. It will be seen that the *individual* is the only term in the series which has a real existence; all the others are mere groups, formed, more or less arbitrarily, by man.

Thus the zoological position of the common frog is expressed as follows:—

Kingdom—ANIMALIA.
  Phylum—VERTEBRATA.
    Class—AMPHIBIA.
      Order—ANURA.
        Family—*Ranidæ*.
          Genus—*Rana*.
            Species—*tigrina*.

Let us now briefly consider some of the reasons which have led zoologists to adopt the system of classification now in general use.

It is obvious that there are various ways in which animals may be classified, and the question arises, which of these, if any, is the right one? Is there any standard by which we can judge of the accuracy of a given classification, or does the whole thing depend

upon the fancy of the classifiers, like the arrangement of books in a library? In other words, are all possible classifications of living things more or less artificial, or is there such a thing as a *natural classification?*

Suppose we were to try to classify all the members of a given family—parents and grandparents, uncles and aunts, cousins, second cousins, and so on. Obviously there are a hundred ways in which it would be possible to arrange them—into dark and fair, tall and short, curly-haired and straight-haired, and so on. But it is equally obvious that all these methods would be purely artificial, and that the only natural way, *i.e.*, the only way to show the real connection of the various members of the family with one another, would be to classify them according to blood-relationship; in other words, to let our classification take the form of a genealogical tree.

Evolution.—There are two theories which attempt to account for the existence of the innumerable species of living things which inhabit the earth: the theory of special *creation* and the theory of *evolution*.

According to the theory of creation, all the individuals of every species existing at the present day—the tens of thousands of dogs, frogs, oak-trees, and what not—are derived by a natural process of descent from a single individual, or from a pair of individuals—in each case precisely resembling, in all essential respects, their existing descendants—which came into existence by a process outside the ordinary course of nature and known as creation. On this hypothesis each species of frog is derived from a common ancestral pair which came into existence, independently of the progenitors of all the other species, at some previous period of the earth's history.

Notice that on this theory the various species of frogs

are no more actually *related* to one another than is either of them to a newt, or, for the matter of that, to man. The individuals of any one species are truly related since they all share a common descent, but there is no more relationship between the individuals of any two independently created species than between any two independently manufactured chairs or tables. The words affinity, relationship, &c., as applied to different species are, on the theory of creation, purely metaphorical, and mean nothing more than that a certain likeness or community of structure exists; just as we might say that an easy chair was more nearly related to a kitchen chair than either of them to a three-legged stool.

We see, therefore, that on the hypothesis of creation, the varying degrees of likeness and unlikeness between the species receive no explanation, and that we get no absolute criterion of classification: we may arrange our organisms, as nearly as our knowledge allows, according to their resemblances and differences, but the relative importance of the characters relied on becomes a purely subjective matter.

According to the rival theory—that of **Descent** or **Organic Evolution,** with which the name of Darwin is inseparably connected—every species existing at the present day is derived by a natural process of descent from some other species which lived at a former period of the world's history. If we could trace back from generation to generation the individuals of any existing species, we should, on this hypothesis, find their characters gradually change, until finally a period was reached at which the differences were so considerable as to necessitate the placing of the ancestral forms in a different species from their descendants at the present day. And in the same way, if we could trace back the species of any one genus, we should find them gradually

approach one another in structure until they finally converged in a single species, differing from those now existing, but standing to all in a true parental relation.

It will be seen that, on this hypothesis, the relative likeness and unlikeness of the various species of frogs are explained as the result of their descent with greater or less modification or *divergence of character* from the ancestral form: and that we get an arrangement or classification in the form of a genealogical tree, which, on this hypothesis, is a strictly natural one, since it shows accurately the relationship of the various species to one another and to the parent stock. So that, on the theory of evolution, a natural classification of any given group of allied organisms is simply a genealogical tree.

Recapitulation Theory.—The proofs for the Doctrine of Evolution, which is now the accepted creed of most biologists, as also some of the explanations or theories as to how Evolution takes place, will be dealt with in Part II, Chapter XIV, after you have studied a number of other kinds of animals, but we might here attempt to explain why a frog first becomes a tadpole with definite fish-like characters (gills, gill-slits, tail, &c.). You have seen that the frog begins life as a single cell, and that it is possible to trace a series of modifications which gradually convert the unicellular oosperm into a tadpole—which is to all intents and purposes a fish—and that the tadpole subsequently undergoes metamorphosis into the more highly organised frog. According to the *theory of recapitulation,* these facts indicate that the frog repeats, during its single life, the series of changes passed through by its ancestors in the course of ages. In other words, **ontogeny**, or the evolution of the individual, is, in its main features, a recapitulation of **phylogeny**, or the evolution of the race. This does not mean that there is any known fish which definitely

resembles the tadpole. The mud-fishes of Africa and America approach in their structure, and the younger stages of these fish show a closer resemblance with the tadpole, thus indicating that the ancestors of these mud-fish and of the frogs must have been a group of primitive and generalised type, possessing characters common to both, which characters are clearly retained in the larval development of the frog. You must bear in mind, however, that it is not always an easy matter to determine which characters are of phylogenetic significance, and which have been secondarily acquired owing to various causes. To take an example: the horny jaws of the tadpole might be taken to indicate that frogs were descended from ancestors with horny jaws and without teeth, though in all probability these organs have been secondarily acquired as *adaptations* in connection with the habits of the tadpole, and have, therefore, unlike the gills, for instance, no ancestral significance.

General Characters and Classification.—Before closing this part, let us summarise the general characters of the class Amphibia, which we have learnt in various preceding chapters from the study of the Frog and a cursory examination of some of the related forms. The Amphibia are Vertebrates, which possess gills either in the larval state only or throughout life, and usually breathe by lungs in the adult condition. The skin is glandular, and usually without an exoskeleton. Lateral line sense-organs (see Part II, Chapter VIII) and median fins not supported by fin-rays are present at some period of life. The paired appendages are pentadactyle limbs, the digits being usually devoid of claws. The skull articulates with the first vertebra by paired occipital condyles borne on the exoccipitals. Certain bones present in the skulls of members of other classes of Vertebrata,

e.g., basi-occipital and supra-occipital, are usually, and basi-sphenoid always, absent: there is a large parasphenoid and there are well-developed squamosals. Large hyoid and branchial arches persist throughout life, or undergo more or less degeneration and give rise to the tongue-cartilage. The blood is about the same temperature as the surrounding medium, and contains large oval nucleated red corpuscles. The heart has a sinus venosus, right and left auricles, a single ventricle, and a truncus arteriosus. The efferent ducts of the testis open into the urinary tubules, and the mesonephric duct (see Part II, Chapter XI) of the male is a urinogenital duct. In the female the mesonephric ducts serve as ureters, and the oviducts are pronephric ducts with cœlomic apertures. The pronephros is the functional kidney in the larva, the mesonephros in the adult. There are a cloaca and an allantoic urinary bladder. Development is usually accompanied by a metamorphosis, the young being hatched as a branchiate larva.

The class Amphibia consists of the following orders:—

Order **Urodela.** Amphibia which retain the tail throughout life. There are usually two pairs of limbs of approximately equal size, including—

(*a*) Those forms which retain the gills throughout life, *e.g.*, *Proteus* and *Siren*.

(*b*) Those forms in which the gills are lost in the adult, *e.g.*, Newts and Salamanders.

Order **Anura.** Amphibia having no tail in the adult condition. The trunk is short and broad, and the hind-limbs greatly exceed the fore-limbs in size. Gills and gill-slits never present in the adult.

Including Frogs and Toads.

Order **Gymnophiona.** Snake-like Amphibia having neither limbs nor tail. A dermal exoskeleton is present. There are no gills or gill-slits in the adult.

PART II

CHAPTER I

AMŒBA: UNICELLULAR AND MULTICELLULAR ANIMALS: DIFFERENCES BETWEEN ANIMALS AND PLANTS

FROM your study of the frog you will have learnt some of the more important facts with regard to the morphology and physiology of a comparatively highly organised animal, and will have overcome a number of preliminary difficulties in acquiring a knowledge of zoological terminology and technique. You will now, therefore, be in a better position to undertake a systematic and comparative examination of a number of other animals—some much less complicated, some more complicated, than the frog—working upwards from the simple to the complex forms. In doing so, you must continually bear in mind the deductions in connection with the theory of evolution referred to in the previous chapter.

Amœba.—Let us begin with a very instructive animalcule belonging to the genus *Amœba*. Amœbæ are often found in the slime at the bottom of pools of stagnant water, adhering to weeds and other submerged objects. They are mostly invisible to the naked eye, rarely exceeding $\frac{1}{4}$ of a millimetre ($\frac{1}{100}$th inch) in diameter, so that it is necessary to examine them entirely by the aid of the microscope. Though they can be seen and recognised with the low power, the high power is necessary for the accurate examination of their structure.

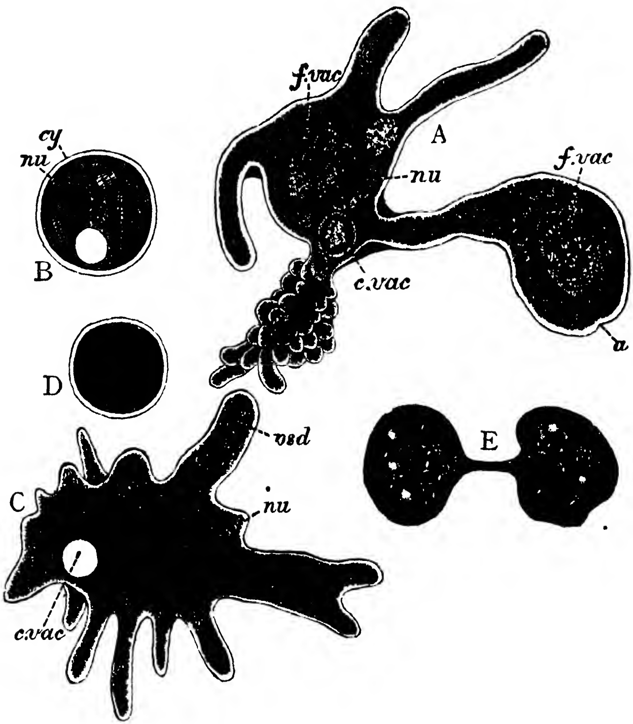

FIG 75.—A, *Amœba proteus*, a living specimen, showing large irregular pseudopods, nucleus (*nu*), contractile vacuole (*c vac*), and two food-vacuoles (*f vac*), each containing a small infusor (see Chapter II) which has been ingested as food The letter *a* to the right of the figure indicates the place where two pseudopods have united to enclose the food vacuole The contractile vacuole in this figure is supposed to be seen through a layer of granular protoplasm, whereas in B and C it is seen in optical section, and therefore appears clear (× about 300)

B, an encysted Amœba, showing cell-wall or cyst (*cy*), nucleus (*nu*), clear contractile vacuole, and three microscopic plants (diatoms) ingested as food

C, *Amœba proteus*, a living specimen, showing several large pseudopods (*psd*), single nucleus (*nu*) and contractile vacuole (*c vac*), and numerous food-particles embedded in the granular endoplasm. (× 330)

D, nucleus of the same after staining, showing a ground substance containing deeply-stained granules of chromatin, and surrounded by a distinct membrane (× 1010).

E, *Amœba proteus*, in the act of multiplying by binary fission (× 500)

(From Parker's *Biology*: C and D after Gruber; A and E after Leidy; B after Howes)

Anatomy.—Examined under the high power (Fig. 75), the Amœba appears like a little shapeless blob of jelly, nearly or quite colourless, and closely resembling a colourless blood-corpuscle or leucocyte of one of the higher animals (p. 111). The central part of it, or *endoplasm*, is granular and semi-transparent—something like ground-glass—while surrounding this inner mass is a border of perfectly transparent and colourless substance—the *ectoplasm*.

One very noticeable thing about the Amœba is that, like the leucocyte, it is never of quite the same form for long together, owing to the protrusion of *pseudopods* (*psd*), by means of which it creeps along slowly. The occurrence of *amœboid movements* is alone sufficient to show that it is an *organism*, or living thing, and no mere mass of dead matter. Moreover, it consists of *protoplasm*, and encloses a *nucleus* (A--D, *nu*) containing *chromatin* and rendered more apparent by staining. The Amœba is therefore a *cell* (compare pp. 112 and 116).

A very important difference is thus at once seen between the Amœba and the frog: the Amœba is *unicellular*, *i.e.*, it consists of a single cell, while the frog is, as we have seen, a *multicellular* animal, built up of innumerable cells which are incapable of an independent existence for any length of time.

Besides the nucleus, there is another structure frequently visible in the living Amœba and not present in the leucocyte. This is a clear, rounded space in the protoplasm (*c. vac*), which periodically disappears with a sudden contraction and then slowly reappears, its movements reminding one of the beating of a minute colourless heart. It is called the *contractile vacuole*, and consists of a cavity containing a watery fluid.

Physiology.—We must now study the physiology of

our animalcule. First of all, as we have already seen, it is *contractile:* although it has no muscles, it can move about from place to place. Its movements, like the voluntary movements of the frog (pp. 8, 182), may occur without the application of any external stimulus, *i.e.*, they are *spontaneous* or *automatic;* or they may be induced by external stimuli—by a sudden shock or by coming in contact with an object suitable for food. Movements of this latter kind, like those resulting from the stimulation of the nerves in a brainless frog, are the result of the *irritability* of the protoplasm; the animalcule is therefore both automatic and irritable, although it possesses neither nerves nor sense-organs.

Under certain circumstances an Amœba temporarily loses its power of movement, draws in its pseudopods, and becomes a globular mass around which is formed a thick, shell-like coat, called the *cyst* or *cell-wall* (Fig. 75, B, *cy*). This is formed by the protoplasm by a process of *secretion* (p. 138); its composition is not known; it is certainly not protoplasmic, and very probably consists of some nitrogenous substance allied in composition to horn and to the *chitin* (see Chapter VI) which forms the external shell of crustaceans, insects, &c.

The formation of the cyst is probably of great importance in preserving the animalcule from destruction by drought, so that should the pool in which it is living dry up, it may still remain alive, protected by its shell-like case, until the conditions for its active life are once more restored; it escapes by the rupture of the cyst, sometimes having first divided into numerous young Amœbæ.

Very often an Amœba in the course of its wanderings comes in contact with a still smaller organism of some kind or other. When this happens the Amœba may be

seen to extend itself round the lesser organism until the latter becomes sunk in its protoplasm in much the same way as a marble might be pressed into a lump of clay or a drop of honey or treacle may flow round an ant (Fig. 75, A, *a*). The diatom or other organism becomes in this way completely enclosed in a cavity or *food vacuole* (*f. vac*), which also contains a small quantity of water necessarily included with the prey. The latter is taken in by the Amœba as food: so that the Amœba, like the frog, *feeds*. It is to be noted that the reception of food takes place in a particular way, viz., by *ingestion*—*i.e.*, it is enclosed entire by the organism.

When the prey is thus ingested, its protoplasm becomes *digested*, any insoluble portions being passed out or *egested*, as fæces (pp. 9 and 78), from the surface of the Amœba as it creeps slowly on. Note that all this is done without either ingestive aperture (mouth), digestive cavity (stomach), or egestive aperture (anus). the food is simply taken in by the flowing round it of protoplasm, digested as it lies enclosed in the protoplasm, and those portions for which it has no further use are got rid of by the Amœba flowing away from them.

We have seen that the frog possesses certain digestive glands, the function of which is to secrete *digestive fluids* which have an important chemical action on the food swallowed, rendering it soluble and diffusible before it passes through the epithelial cells of the enteric canal into the blood: the gastric juice, for example, has the power of converting proteins into peptones by means of the ferment pepsin (p. 77); the digestion here takes place *outside* the cells, *i.e.*, is *extracellular*. There can be little doubt that the protoplasm of Amœba is able to render that of its prey soluble and diffusible by the agency of some substance analogous to pepsin, and that the dissolved matters diffuse through the body of

the Amœba until the latter is, as it were, soaked through and through with them. The process of digestion in Amœba thus takes place within a single cell, *i.e.*, it is *intracellular.*

It has been proved by experiment that proteins are the only class of food which Amœba can make use of: it is unable to digest either starch or fat (p. 75). Mineral matters must, however, be taken with the food in the form of a weak watery solution, since the water in which the animalcule lives is never absolutely pure.

The Amœba being thus permeated, as it were, with a nutrient solution, the elements of the solution, hitherto arranged in the form of peptones, mineral salts, and water, become rearranged in such a way as to form new particles of living protoplasm, which are deposited among the pre-existing particles. In a word, the food is *assimilated*, or converted into the actual living substance of the Amœba, which must therefore grow, if nothing happens to counteract this formation of new protoplasm.

We have seen, however, that work results in a proportional amount of waste (p. 69), and just as in the frog or in ourselves, every movement of the Amœba, however slight, is accompanied by a proportional oxidation or low temperature combustion of the protoplasm, *i.e.*, the constituents of the protoplasm combine with oxygen, forming waste or excretory matters—carbon dioxide, water, and certain nitrogenous substances of simpler constitution than proteins, such as urea. These products of *excretion*, formed in the case of Amœba without the agency of any special excretory organs (*e.g.*, kidneys), are given off partly from its general surface, but partly, it would seem, by the agency of the contractile vacuole, by means of which the water taken in with the food is also got rid of.

With this breaking down of proteins the vital activities of all organisms are invariably connected. Just as useful mechanical work may be done by the fall of a weight from a given height to the level of the ground, so the work done by the organism is a result of its complex proteins falling, so to speak, to the level of simpler substances. In both instances potential energy or energy of position is converted into kinetic or actual energy.

The statement just made that the protoplasm of Amœba constantly undergoes oxidation presupposes a constant supply of oxygen. The water in which the animalcule lives invariably contains that gas in solution, and diffusion takes place, oxygen passing into the interior of the Amœba while carbon dioxide passes out into the water. This is the process of breathing or *respiration* (p. 152), and it occurs in Amœba without the agency of special respiratory organs. Thus the carbon dioxide is got rid of, and at the same time a supply of oxygen is obtained for further combustion. The oxidation of the protoplasm of the Amœba is doubtless accompanied by an evolution of heat, as in higher animals (p. 160), although this has never been proved.

We thus see that a very elaborate series of chemical processes is constantly going on in the interior of Amœba, as in the frog; the whole series of which is spoken of collectively as *metabolism—constructive* and *destructive* (p. 157). Living protoplasm is thus the most unstable of substances; it is never precisely the same thing for two consecutive seconds; its existence, like that of a waterfall or a fountain, depends upon the constant flow of matter into it and away from it.

It follows from what has been said that if the income of an Amœba, *i.e.*, the total weight of substances taken

in (food *plus* oxygen *plus* water), is greater than its expenditure or the total weight of substances given out (fæces *plus* excreta proper *plus* carbon dioxide), the animalcule will grow: if less it will dwindle away: if the two are equal it will remain of the same weight or in a state of physiological equilibrium.

Reproduction.—It is evident that Amœba must also be able to perform the function of *reproduction*. You have learnt that the cells of the frog multiply by *simple* or *binary* fission (p. 112): the nucleus first divides into two, and then the surrounding protoplasm; and precisely the same thing occurs in Amœba (Fig. 75, E), the reproduction of which therefore takes place by the simplest method known, without any special reproductive organs. The animalcule simply divides into two Amœbæ, each exactly like itself, and in doing so ceases to exist as a distinct individual. Instead of the successive production of offspring from an ultimately dying parent, we have the simultaneous production of offspring by the division of the parent, which does not die, but becomes simply merged in its progeny. There can be no better instance of the fact that reproduction is discontinuous growth.

From this it seems that an Amœba, unless suffering a violent death, is practically "immortal," since it divides into two completely organised individuals, each of which begins life with half of the entire body of its parent, there being therefore nothing left of the latter to die: it therefore appears certain that "death has no place as a natural recurrent phenomenon" in that organism. In multicellular forms it is only the reproductive cells which are, physically, potentially immortal.

It is said that occasionally two Amœbæ come into contact and undergo fusion, just as the gametes of the frog (sperm and ovum) unite in the processes of fertilisation

(p. 209). This process of *conjugation*—which probably precedes encystment and *multiple fission* (see p. 244)—will be referred to again in the following chapters, and it is important to bear in mind that reproduction can take place quite independently of such a process.

Amœbæ may also be propagated artificially. If a specimen is cut into pieces, each fragment is capable of developing into a complete animalcule provided it contains a portion of nuclear matter, but not otherwise From this it is obvious that the nucleus exerts an influence of the utmost importance over the vital processes of the organism.

If an Amœba does happen to be killed and to escape being eaten it will, like a dead frog, undergo gradual decomposition, becoming converted into various simple substances of which carbon dioxide, water, and ammonia are the chief (p. 160).

Death results if the temperature to which an Amœba is exposed reaches about 40° C., and at freezing point its movements cease entirely and it becomes inert.

Unicellular and Multicellular Organisms.—We thus see that complex organs, composed of various tissues, each consisting of cells of characteristic form, are not necessary in order that the vital functions may be performed: the only essential is nucleated protoplasm. As we pass from the unicellular Amœba to the higher multicellular animals we shall find—just as we found in tracing the development of the frog from the unicellular oosperm (p. 217)—that a *differentiation of structure* accompanied by a *division of physiological labour* becomes more and more marked, some cells giving rise to organs of locomotion, others to organs of reproduction, and so on. But every function necessary

for the life of an animal—or a plant—is due in the first instance to protoplasm, and a simple cell, like the Amœba, can perform them all.

Differences between Animals and Plants.—It will be useful for the student to institute a comparison between Amœba and any unicellular plant organism, such as *Sphærella* or *Protococcus* or the individual cells of a filamentous alga like *Spirogyra,* that he may have studied in his Botany course. He will remember that in those plant-cells there is no change of form as in Amœba, the protoplasm being surrounded by a definite *cell-wall* consisting of *cellulose,*—a carbohydrate allied in composition to starch, sugar, etc., from which substances, however, it can be easily distinguished with the help of certain chemical reagents. Even when Amœba is in the encysted condition, the cyst, as stated above (p. 244), is very probably of some nitrogenous substance. In the matter of nutrition, the differences between Sphærella and Amœba are very marked, and indeed fundamental. As is well known, these tiny plants, like other green plants, cannot and do not swallow any solid food, but live on water containing various mineral salts and carbon dioxide in solution. They absorb these substances, and in their body build up simple carbohydrates, for which purpose the green chlorophyll contained in their body and the energy supplied by sunlight are essential. The process is known as photosynthesis, and is accompanied by the evolution of oxygen gas. The carbohydrates thus formed unite with the ammonia salts or the nitrates absorbed from the surrounding water, the result being the formation of some comparatively simple nitrogenous compound. Then further combinations take place, substances of greater and greater complexity are produced, sulphur from the absorbed sulphates enters

into combination, and proteins are formed. From these, finally, fresh living protoplasm arises.

As in Amœba, the final result of the nutritive process is the manufacture of protoplasm, and this result is attained by the formation of various substances of increasing complexity. But it must be noted that the steps in this process of constructive metabolism are widely different in the two cases. In Amœba we start with living protoplasm—that of the prey—which is killed and broken up into diffusible proteins, these being afterwards re-combined to form new molecules of the living protoplasm of Amœba. So that the food of Amœba is, to begin with, as complex as itself, and is first broken down by digestion into simpler compounds, these being afterwards re-combined into more complex ones. In Sphærella, on the other hand, we start with extremely simple compounds, such as carbon dioxide, water, nitrates, sulphates, &c. Nothing which can be properly called digestion, *i.e.*, a breaking up and dissolving of the food, takes place, but its various constituents are combined into substances of gradually increasing complexity, protoplasm, as before, being the final result.

To express the matter in another way: Amœba can only make protoplasm out of proteins already formed by some other organism: Sphærella can form it out of simple liquid and gaseous inorganic materials.

Speaking generally, it may be said that these two methods of nutrition are respectively characteristic of the two great groups of living things. Animals require solid food containing ready-made proteins, and cannot build up their protoplasm out of simpler compounds. Green plants, *i.e.*, all the ordinary trees, shrubs, weeds, &c., take only liquid and gaseous food, and build up their protoplasm out of carbon dioxide, water, and

mineral salts. The first of these methods of nutrition is conveniently distinguished as *holozoic*, or wholly-animal, the second as *holophytic*, or wholly-vegetal.

As in Amœba, destructive metabolism is constantly going on side by side with constructive. The protoplasm becomes oxidised, water, carbon dioxide, and nitrogenous waste matters being formed and finally got rid of. Obviously, then, absorption of oxygen must take place, or, in other words, respiration must be one of the functions of the protoplasm of Sphærella as of that of Amœba. In many green, *i.e.*, chlorophyll-containing, plants, this has been proved to be the case: respiration, *i.e.*, the taking in of oxygen and giving out of carbon dioxide, is constantly going on, but during daylight is obscured by the converse process—the taking in of carbon dioxide for nutritive purposes and the giving out of the oxygen liberated by its decomposition. In darkness, when this latter process is in abeyance, the occurrence of respiration is more readily ascertained.

Owing to the constant decomposition, during sunlight, of carbon dioxide, a larger volume of oxygen than of carbon dioxide is evolved; and if an analysis were made of all the ingesta of the organism (carbon dioxide *plus* mineral salts *plus* respiratory oxygen) they would be found to contain less oxygen than the egesta (oxygen from decomposition of carbon dioxide *plus* water, excreted carbon dioxide, and nitrogenous waste); so that the nutritive process in Sphærella is, as a whole, a process of deoxidation. In Amœba, on the other hand, the ingesta (food *plus* respiratory oxygen) contain more oxygen than the egesta (fæces *plus* carbon dioxide, water, and nitrogenous excreta), the nutritive process being therefore on the whole one of oxidation. This difference is, speaking broadly, characteristic of plants and animals generally; animals, as a rule, take in more

free oxygen than they give out, while green plants always give out more than they take in.

Destructive metabolism is, however, manifested not only in the formation of waste-products, but in that of substances simpler than protoplasm which remain an integral part of the organism, viz., cellulose and starch. The cell-wall is probably formed by the conversion of a thin superficial layer of protoplasm into cellulose, the cyst attaining its final thickness by frequent repetition of the process.

We see then that destructive metabolism may result in the formation of (*a*) *waste products* and (*b*) *plastic products*, the former being got rid of as of no further use, while the latter remain an integral part of the organism.

We have seen that typical animal-cells, such as those of the frog (Part I, Chap. VII) are not provided with a cellulose cell-wall and do not contain chlorophyll. It is characteristic, on the other hand, of most plant-cells—which also consist of nucleated protoplasm—that they are surrounded with a cellulose cell-wall, and that, in the case of green plants, they contain chlorophyll. Speaking generally, the nutrition of animals is holozoic, and that of green plants holophytic; and in correspondence with this difference in the character of the food, most animals have an ingestive aperture or mouth for taking in the solid food, and some kind of digestive cavity, either permanent (stomach) or temporary (food-vacuole); they also have, as a rule, some kind of excretory apparatus. Moreover, animals are usually capable of automatic movement, while in most plants the organism, as a whole, exhibits no automatism, but only the slow movements of growth.

In the next two chapters we shall study certain other unicellular organisms which show an advance on

Amœba in possessing a certain amount of morphological and physiological differentiation But the structural differentiations, as they are merely parts of one cell, cannot be spoken of as "organs" in the sense in which we have used the word hitherto, as they are not composed of numerous cells. They are, however, organs in the physiological sense, as they perform different functions.

PRACTICAL DIRECTIONS[1]

Amœba.

Examine a drop of water from the bottom of a pond, with the low power, first putting on a cover-glass, and look for Amœbæ: if the water does not contain small particles of sand or mud, place a small piece of thin paper under the edge of the cover so as to avoid crushing the organisms. When you have found a specimen, note—

1 The *irregular and changing form* of the animal, the protoplasm running out into blunt *pseudopods*

2. The granular character of the protoplasm, the granules usually not extending to the periphery, so that a clear

[1] You should, if possible, try to obtain specimens of Amœbæ and the other fresh-water organisms described in this and the two following chapters for yourself, by collecting stagnant pond-water, together with a little of the mud at the bottom and some water-weeds, and letting it stand for a few days in a glass jar or bottle. If you are unable to find Amœba in natural collections of water, you can take in a cup some clean water from the tap and put some dry leaves in it, and keep it uncovered. As the leaves rot in the water, a good medium will be formed for Amœba and other organisms to flourish in. Evidently encysted Amœbæ existing in the air or sticking to the surface of the leaves, on finding suitable conditions, become active again and propagate their kind immensely. In such an artificial culture the first organisms to arise will be Bacteria of different sorts, and then, after forty-eight hours or more, Amœbæ of an elongated, vermicular form (*Amœba limax*) will be found. As other organisms develop later on, Amœbæ become very scarce, as they are made use of as food by these other organisms. It is important that the culture should be examined from day to day, and water given to the class for examination on the day that Amœbæ are found to be very plentiful.

ectoplasm can be distinguished from a granular *endoplasm*. The granules render the flowing movements of the protoplasm visible.

3. The *food-vacuoles* in the protoplasm, containing fluid, and often also food-particles.

4. The *contractile vacuole*, containing fluid, and its rhythmical contractions

5. The protrusion and retraction of the pseudopods Sketch a specimen several times at short intervals, noting the direction in which the granules flow. Then put on the high power. Go over §§ 1—5 again, and make a detailed sketch

6. Look out for specimens undergoing *multiplication by binary fission*, and also for *encysted* individuals.

7. Run a little dry carmine or indigo under the cover-glass, and note that the particles can be taken in at all parts of the surface

8. Take another drop, and after verifying that there are some Amœbæ in it, put a drop of acetic methyl-green or acetic iodine-green (1 per cent. acetic acid to which a trace of methyl-green or iodine-green has been added) near one edge of the cover-glass and apply a piece of filter-paper at the opposite edge of the cover-glass. This will kill the animal, and render the *nucleus* distinct.

9 *Permanent preparations*, showing the nucleus, may be made on the slide as follows :—

Place a drop of water containing Amœbæ on a slide, and soak up with blotting-paper as much of the water as is possible without carrying the Amœbæ along with it Fix (see p. 145) with a drop of absolute alcohol, stain (a staining-fluid called picrocarmine is better than borax-carmine for this purpose), wash carefully with weak and then with absolute alcohol, and add a drop of turpentine or xylol—or better, oil of cloves. Soak off the excess of oil of cloves with blotting-paper, and mount in Canada balsam. It will, however, be a difficult task for the elementary student to make permanent preparations of Amœba.

CHAPTER II

PARAMECIUM: BIOGENESIS AND ABIOGENESIS: VORTICELLA AND ITS ALLIES—COLONIAL ORGANISMS

We have now to consider certain organisms in which differentiation has gone much further than in the unicellular forms already considered: which have, in fact, acquired many of the characteristics of the higher animals and plants while remaining unicellular (compare p. 254). The study of several of these more or less highly differentiated though unicellular forms will occupy the present chapter.

It was mentioned above that, in the earlier stages of the putrefaction of an organic infusion, Bacteria only were found, and that, later, Amœba and various other animal organisms made their appearance (p. 254). Among these latter are much larger organisms, generally of an ovoidal form, moving about very quickly and seen by the use of a high power to be covered with innumerable fine cilia. These are called *ciliate Infusoria;* many kinds are common in putrefying infusions, some occur in the intestines of the higher animals, while others are among the commonest inhabitants of both fresh and salt water.

Paramecium.—A very common ciliate infusor is the beautiful "slipper-animalcule," *Paramecium,* which

from its comparatively large size and from the ease with which all essential points of its organisation can be made out is a very convenient and interesting object of study.

Compared with the majority of the organisms which have come under our notice it may fairly be considered as gigantic, being no less than $\frac{1}{5}$–$\frac{1}{3}$ mm. (200–330μ) in length: in fact it is just visible to the naked eye as a minute whitish speck.

Form.—Its form (Fig. 76) can be fairly well imitated by making out of clay or stiff dough an elongated cylinder rounded at one end and bluntly pointed at the other; then giving the broader end a slight twist; and finally making on the side rendered somewhat concave by the twist a wide, shallow groove beginning at the broad end and gradually narrowing to about the middle, where it ends in a tolerably deep depression.

The groove is called the *buccal groove*: at the posterior end of the groove is a small aperture, the mouth, which, however, leads directly into the soft internal protoplasm by a *gullet*. The surface of the creature on which the groove is placed is distinguished as the ventral surface, the opposite surface being upper or dorsal; the broad end is anterior, the narrow end posterior, the former being directed forwards as the animalcule swims. These descriptive terms being decided upon, it will be seen that the buccal groove begins on the left side, and gradually curves over to the middle of the ventral surface.

As the creature swims its form is seen to be permanent, exhibiting no contractions of either an amœboid or a euglenoid nature. It is, however, distinctly flexible, often being bent in one or other direction when passing between obstacles, such as entangled masses of weed. This permanence of contour is due to the presence of a

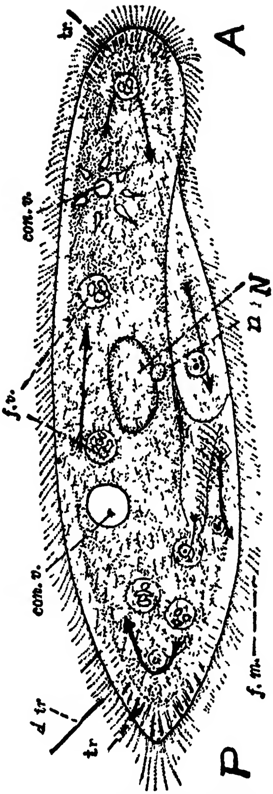

FIG 76.—*Paramecium caudatum.* *A*, anterior end, *con v*, contractile vacuoles, the anterior one showing the radiating canals which feed the vacuole, *d.tr*, discharged trichocyst, *f v*, food vacuoles, *f m*, fæcal matter which is discharged from the body at a definite spot, *N*, macronucleus, *n*, micronucleus, *P*, posterior end, *tr* trichocyst before discharge. Arrows indicate the direction and course of the food vacuoles within the endoplasm × 375. (From Hegner and Taliaferro's *Protozoology*, after Dahlgren and Kepner.)

tolerably firm though delicate *cuticle* which invests the whole surface.

Structure.—The protoplasm thus enclosed by the cuticle is distinctly divisible into two portions—an external somewhat dense layer, the *cortical layer* or *ectoplasm* (*cort*), and an internal more fluid material, the *medullary substance* or *endoplasm*. It will be remembered that a somewhat similar distinction of the protoplasm into two layers is exhibited by Amœba (p. 243), the ectoplasm being distinguished from the endoplasm simply by the absence of granules. In Paramecium the distinction is a far more fundamental one: the cortex is radially striated and is comparatively firm and dense, while the medulla is granular and semi-fluid, as may be seen from the fact that food-particles (*f. vac*, and see p. 261) move freely in it, whereas they never pass into the cortex. The medulla has a reticular structure similar to that of

the protoplasm of the ordinary animal-cell, consisting of a delicate granular network the meshes of which are filled with a transparent material. In the cortex the meshes of the network are closer, and so form a comparatively dense substance. The deeper part of the cortex also exhibits longitudinal striations, called *myophan striations*, which are due to longitudinal wrinkling of the under surface of the cortex.

The mouth leads into a short funnel-like tube, the gullet, which is lined by cuticle and passes through the cortex to end in the soft medulla, thus making a free communication between the latter and the external water.

The cilia with which the body is covered are of approximately equal size, quite short in relation to the entire animal, and arranged in longitudinal rows over the whole outer surface. They consist of prolongations of the cortex, and each passes through a minute perforation in the cuticle. They are in constant rhythmical movement, like the cilia on the epithelial cells of the frog's mouth (p. 115), and are thereby distinguished from the flagella of Sphærella, Euglena, &c., which exhibit more or less intermittent lashing movements.

Near the middle of the body, on the inner boundary of the cortex, is a large oval nucleus, the *macronucleus* (Fig. 276, N), and against one side of it, in *P. caudatum*, is a small oval structure (*n*) which is also deeply stained by, *e.g.*, magenta or carmine. This is the *micronucleus*: it is to be considered as a second, smaller nucleus. In the closely allied *P. aurelia* there are two micronuclei.

There are two contractile vacuoles (*con. v.*) in relation with the cortex, one situated at about a third of the entire length from the anterior end of the body, the other at about the same distance from the posterior end.

The action of the contractile vacuoles is very beautifully seen in a Paramecium at rest: it is particularly striking in a specimen subjected to slight pressure under a cover-glass, but is perfectly visible in one which has merely temporarily suspended its active, swimming movements. It is then seen that during the *diastole*, or phase of expansion of each vacuole, a number—about six to ten—of delicate, radiating, spindle-shaped spaces filled with fluid appear round it, like the rays of a star (upper vacuole in Fig. 76): the vacuole itself contracts or performs its *systole*, completely disappearing from view, and immediately afterwards the radiating canals flow together and refill it, becoming themselves emptied and therefore invisible for an instant (lower vacuole in Fig. 76) but rapidly appearing once more. There seems to be no doubt that the water taken into the body is drained into these canals, emptied into the vacuole, and finally discharged to the exterior.

Nutrition.—The process of feeding can be very conveniently studied in Paramecium by placing in the water some finely-divided carmine or indigo. When the creature comes into the neighbourhood of the coloured particles, the latter are swept about in various directions by the action of the cilia: some of them, however, are certain to be swept into the neighbourhood of the buccal groove and gullet, the cilia of which all work downwards, *i.e.*, towards the inner end of the gullet. The grains of carmine are thus carried into the gullet, where for an instant they lie surrounded by the water of which it is full: then, instantaneously, probably by the contraction of the tube itself, the animalcule performs a sort of gulp and the grains with an enveloping globule of water or *food-vacuole* are forced into the medullary protoplasm. This process is repeated again and again, so that in any well-nourished Paramecium there are to be seen

numerous globular spaces filled with water and containing particles of food—or in the present instance of carmine or indigo. At every gulp the newly-formed food-vacuole pushes, as it were, its predecessor before it: contraction of the medullary protoplasm also takes place in a definite direction, and thus a circulation of food-vacuoles is produced, as indicated in Fig. 76, by arrows.

After circulating in this way for some time the water of the food-vacuoles is gradually absorbed, being ultimately excreted by the contractile vacuoles, so that the contained particles come to lie in the medulla itself (refer to figure). The circulation still continues, until finally the particles are brought to a spot situated about half-way between the mouth and the posterior end of the body: here if carefully watched they are seen to approach the surface and then to be suddenly ejected. The spot in question is therefore to be looked upon as a potential *anus*, or aperture for the egestion of fæces or undigested food-matters. It is a potential and not an actual anus, because it is not a true aperture, but only a soft place in the cortex through which, by the contractions of the medulla, solid particles are easily forced.

Of course when Paramecium ingests, as it usually does, not carmine but minute living organisms, the latter are digested as they circulate through the medullary protoplasm, and only the non-nutritious parts cast out at the anal spot. It has been found by experiment that this infusor can digest not only proteins but also starch and perhaps fats. The nutrition of Paramecium is therefore characteristically holozoic.

It was mentioned above that the cortex is radially striated in optical section. Careful examination with a very high power shows that this appearance is due to the presence in it of minute spindle-shaped bodies

(Fig. 76) closely arranged in a single layer and perpendicular to the surface. These are called *trichocysts.*

When a Paramecium is killed, either by the addition of some poisonous reagent or by simple pressure of the cover-glass, it frequently assumes a remarkable appearance. Long delicate threads suddenly appear, projecting from its surface in all directions and looking very much as if the cilia had suddenly protruded to many times their original length. But these filaments have really nothing to do with the cilia; they are contained under ordinary circumstances in the trichocysts, probably coiled up; and by the contraction of the cortex consequent upon any sudden irritation they are projected in the way indicated. In Fig. 76 a few trichocysts (*d.tr.*) are shown in the exploded condition, *i.e.*, with the threads protruded. Most likely these bodies are weapons of offence like the very similar structures (nematocysts) found in polypes (see Chapter IV., Fig. 83).

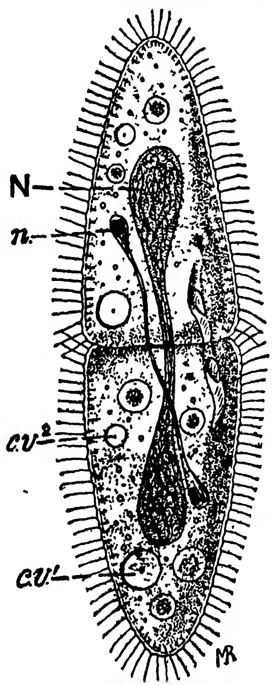

FIG 76A.—*Paramecium caudatum* showing binary fission The macronucleus (*N*) divides by amitosis and the micronucleus (*n*) mitotically $c\,v.^1$, original and $c\,v^2$, new contractile vacuole in one of the daughter individuals. (From Minchin after Butschli and Schewiakoff.)

Reproduction.—Paramecium multiplies by simple fission, the division of the body being always preceded by the elongation and subsequent division of the macro- and micro-nucleus (Fig. 76, A).

Conjugation (pp. 248, 249) also occurs, usually after multiplication by fission has gone on for some time. Two Paramecia come into contact by their ventral faces, and in each of these conjugating individuals or *gametes* the macronucleus takes no part in the process and degenerates, while the micronucleus undergoes a somewhat complicated series of changes; the essential part of the process being the fusion of two products of the division of the micronuclei, one from each gamete, each of which then contains a single nuclear body, the *conjugation-nucleus*, formed by the union of nuclear matter derived from two distinct individuals, and therefore comparable to the nucleus of the oosperm in the higher animals (p. 209). The other products of division of the micronucleus disappear (compare Chapter X.), and new macro- and micro-nuclei arise from the conjugation-nucleus. In this case, however, the two entire gametes do not unite to form a zygote, but separate after the process is complete and begin once more to lead an independent existence, when ordinary transverse fission again takes place. Woodruff has kept up during the last nineteen years, a race of *Paramecium aurelia*, starting from a single "wild" individual, and after his observations on eleven thousand generations of the Paramecium in question, has come to the conclusion that a single cell can reproduce itself indefinitely, under favourable conditions, without recourse to conjugation. During these investigations it has been discovered, that during continued binary fissions of the individuals, sometimes an internal reorganisation of the nuclear apparatus, called endomixis takes place. The macronucleus gradually disintegrates and is absorbed, and a new one is formed from the micronuclear apparatus.

It will be noticed that, in the present instance (see also p. 248), conjugation is not a process of multiplication: it has been ascertained that during the time two

infusors are conjugating each might have produced a very large number of offspring by continuing to undergo fission at the usual rate. The importance of the process lies in the exchange of nuclear material between the two conjugating individuals, which exercises a stimulating function.

Biogenesis and Abiogenesis.—The study of the foregoing living things, and especially of Bacteria, the smallest and probably the simplest of all known organisms (p. 254), naturally leads us to the consideration of one of the most important problems of Biology—the problem of the origin of life.

In all the higher organisms we know that each individual arises in some way or other from a pre-existing individual: no one doubts that every bird now living arose by a process of development from an egg formed in the body of a parent-bird, and that every tree now growing took its origin either from a seed or from a bud produced by a parent-plant. But there have always—until quite recently, at any rate—been upholders of the view that the lower forms of life, Bacteria, Monads, and the like, may under certain circumstances originate independently of pre-existing organisms: that, for instance, in a flask of some organic infusion boiled so as to kill any living things present in it, fresh forms of life may arise *de novo*—may in fact be created then and there.

We have therefore two theories of the origin of the lower organisms, the theory of *Biogenesis*, according to which each living thing, however simple, arises by a natural process of budding, fission, spore-formation, or what not, from a parent organism: and the theory of *Abiogenesis*, or as it is sometimes called *Spontaneous Generation*, according to which fully-formed living organisms sometimes arise from not-living matter.

In former times the occurrence of abiogenesis was

universally believed in. The expression that a piece of meat has "bred maggots"; the opinion that parasites such as the gall-insects of plants or the tape-worms in the intestines of animals originate where they are found; the belief still held in some rural districts that frogs would spring up in large numbers if a dead and dried up frog is pounded and the powder sprinkled over water, or scorpions would be formed if cow-dung and curd are kept in an earthen pot: all indicate a survival of this belief.

As accurate enquiries into these matters were made, the number of cases in which spontaneous generation was supposed to occur was rapidly diminished. It was not surprising, however, considering the rapidity with which Bacteria and Monads were found to make their appearance in organic substances and infusions, that many men of science imagined them to be produced abiogenetically. The rapid multiplication of these forms means, of course, that a certain amount of fresh living protoplasm has been formed out of the constituents of the hay-infusion, through the agency in the first instance of a single living Bacterium. The question naturally arises, Why may not the formation of protoplasm take place independently of this insignificant speck of living matter?

It must not be thought that this question is in any way a vain or absurd one. That living protoplasm has at some period of the world's history originated from not-living matter seems a necessary corollary of the doctrine of evolution, and is obviously the very essence of the doctrine of special creation (p. 235); and there is no *a priori* reason why it should be impossible to imitate the unknown conditions under which the process took place. But at present we are quite unable to solve this fundamental problem.

Experiments conducted with proper precautions, how-

ever, all tell the same tale: they prove conclusively that in putrescible infusions that have been properly *sterilised* —*i.e.*, thoroughly boiled so as to kill any organisms they may contain—and adequately protected from the entrance of atmospheric germs, no micro-organisms ever make their appearance. So that the last argument for abiogenesis has been proved to be fallacious, and the doctrine of biogenesis shown, as conclusively as observation and experiment can show it, to be of universal application as far as existing conditions known to us are concerned. It is also necessary to add that the presence of microbes in considerable quantities in our atmosphere has been proved experimentally.

VORTICELLA.

Vorticella.—The next organism we have to consider is a ciliate infusor, even commoner than that just described. It is hardly possible to examine the water of a pond with any care without finding in it, sometimes attached to weeds, sometimes to the legs of water-fleas, sometimes to the sticks and stones of the bottom, numbers of exquisitely beautiful little creatures, each like an inverted bell with a very long handle, or a wine-glass with a very long stem. These are the well-known "bell-animalcules," the commonest among them belonging to various species of the genus *Vorticella*.

Form and Structure.—The first thing that strikes one about Vorticella (Fig. 77, A) is the fact that it is permanently fixed, like a plant, the proximal or near end of the stalk being always firmly fixed to some aquatic object, while to the distal or far end the body proper of the animalcule is attached.

But in spite of its peculiar form it presents certain very obvious points of resemblance to Paramecium. The protoplasm is divided into cortex (C, *cort*) and

medulla (*med*), and is invested with a delicate cuticle (*cu*). There is a single contractile vacuole (*c. vac*) the movements of which are very readily made out owing to the ease with which the attached organism is kept under observation. There is a macronucleus (*nu*) remarkable for its elongated band-like form, and having in its neighbourhood a minute micronucleus. Cilia are also present, but the way in which they are disposed is very peculiar and characteristic. To understand it we must study the form of the body a little more closely.

The conical body is attached by its apex or proximal end to the stalk: its base or distal end is expanded so as to form a thickened rim, the *peristome* (*per*), within which is a plate-like body elevated on one side called the *disc* (*d*), and looking like the partly raised lid of a chalice. Between the raised side of the disc and the peristome is a depression, the mouth (*mth*), leading into a conical gullet (*gull*).

There is reason for thinking that the whole proximal region of Vorticella answers to the dorsal surface of Paramecium, and its distal surface with the peristome and disc to the ventral surface of the free-swimming genus: the mouth is to the left in both.

A single row of cilia is disposed round the inner border of the peristome and continued on the one hand down the gullet, and on the other round the elevated portion of the disc; the whole row of cilia thus takes a spiral direction. The rest of the body is completely bare of cilia.

The movements of the cilia produce a very curious optical illusion: as one watches a fully-expanded specimen it is hardly possible to believe that the peristome and disc are not actually revolving—a state of things

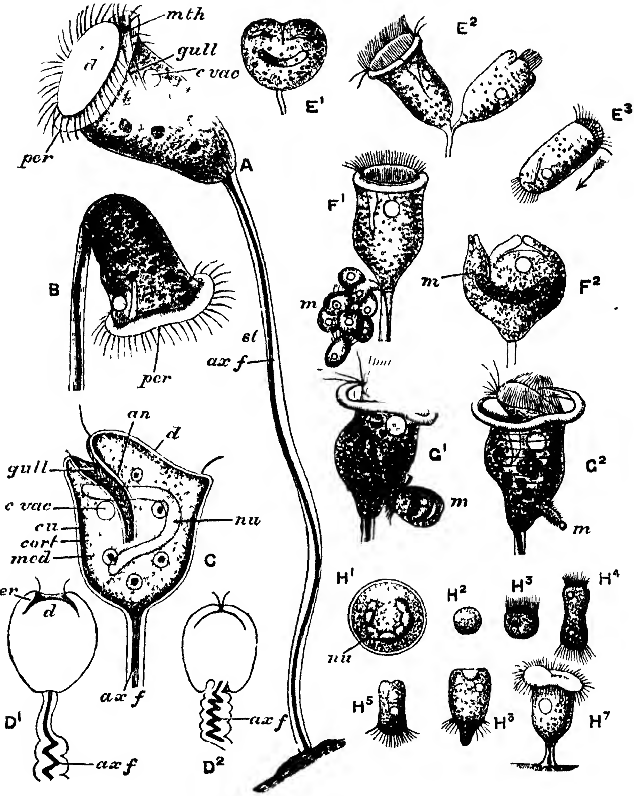

FIG 77 —*Vorticella*

A, living specimen fully expanded, showing stalk (*st*) with axial fibre (*ax f*), peristome (*per*), disc (*d*), mouth (*mth*), gullet (*gull*), and contractile vacuole (*c vac*) (× 250)

B, the same, bent on its stalk and with the disc turned away from the observer

C, optical section of the same, showing cuticle (*cu*), cortex (*cort*), medulla (*med*), macronucleus (*nu*), gullet (*gull*), several food vacuoles and anal spot (*an*), as well as the other structures shown in A

D¹, a half-retracted, and D² a fully retracted specimen, showing the coiling of the stalk and overlapping of the disc by the peristome

E¹ commencement of binary fission, E², completion of the process, E³, the product of division swimming freely in the direction indicated by the arrow

F¹, a specimen dividing into a macrozooid and several microzooids (*m*), F², division into one macro- and one micro-zooid

G¹, G², two stages in conjugation, showing the gradual absorption of the micro gamete (*m*) into the macrogamete

H¹, multiple fission of encysted form, the nucleus dividing into numerous masses, H², spore formed by multiple fission, H³–H⁶ development of the spore H⁷ is undergoing binary fission (From Parker's *Biology* H after Savile-Kent.)

which would imply that they were discontinuous from the rest of the body. As a matter of fact the appearance is due to the successive contraction of all the cilia in the same direction, and is analogous to that produced by a strong wind on a field of corn or long grass. The bending down of successive blades of grass produces a series of waves travelling across the field in the direction of the wind. If instead of a field we had a large circle of grass, and if this were acted upon by a cyclone, the wave would travel round the circle, which would then appear to revolve.

Nutrition.—Naturally the movement of the circlet of cilia produces a small whirlpool in the neighbourhood of the Vorticella, as can be seen by introducing finely-powdered carmine into the water. It is through the agency of this whirlpool that food particles are swept into the mouth, surrounded, as in Paramecium, by a globule of water: the food-vacuoles (C) thus constituted circulate in the medullary protoplasm and the non-nutritive parts are finally egested at an anal spot (*an*) situated near the base of the gullet.

Contractility and Irritability.—The stalk (A, *st*) consists of a very delicate, transparent, outer substance, which is continuous with the cuticle of the body and contains a delicate *axial fibre* (*ax. f*) running along it from end to end in a somewhat spiral direction. This fibre is a prolongation of the cortex of the body (C): under a very high power it appears granular or delicately striated, the striæ being continued into the cortex of the proximal part of the body.

A striking characteristic of Vorticella is its extreme irritability, *i.e.*, the readiness with which it responds to any external stimulus. The slightest jar of the microscope, the contact of some other organism, or even a current of water produced by some free-swimming form

like Paramecium, is felt directly by the bell-animalcule, and is followed by an instantaneous change in the relative position of its parts. The stalk becomes coiled into a close spiral so as to have a mere fraction of its original length, and the body from being bell-shaped becomes globular, the disc being withdrawn and the peristome closed over it (D^1, D^2).

The coiling of the stalk leads us to the consideration of the particular form of contractility called *muscular*, which is met with in multicellular animals, *e.g.*, the frog (p. 64). It was mentioned above that while the stalk in its fully expanded condition is straight, the axial fibre is not straight, but forms a very open spiral, *i.e.*, it does not lie in the centre of the stalk, but at any transverse section is nearer the surface at one spot than elsewhere, and this point as we ascend the stalk is directed successively to all points of the compass.

Now suppose that the axial fibre undergoes a sudden contraction, that is to say, a decrease in length accompanied by an increase in diameter, since, as we have already seen, there is no decrease in volume in protoplasmic contraction. There will naturally follow a corresponding shortening of the elastic cuticular substance which forms the outer layer of the stalk. If the axial fibre were entirely towards one side of the stalk, the result of the contraction would be a flexure of the stalk towards that side, but, as its direction is spiral, the stalk is bent successively in every direction, that is, is thrown into a close, spiral coil.

The axial fibre is therefore a portion of the protoplasm which possesses the property of contractility in a special degree; in which, moreover, contraction takes place in a definite direction—the direction of the length of the fibre—so that its inevitable result is to shorten the fibre and consequently to bring its two ends nearer together.

This is the essential characteristic of a muscular contraction, and the axial fibre in the stalk of Vorticella is therefore to be looked upon as the first instance of a clearly differentiated *muscle* which has come under our notice amongst unicellular animals.

Reproduction.—There are some interesting features in the reproduction of Vorticella. It multiplies by binary fission, dividing through the long axis of the body (E^1, E^2). Hence it is generally said that fission is longitudinal, not transverse, as in Paramecium. But on the theory (p. 267) that the peristome and disc are ventral and the attached end dorsal, fission is really transverse in this case also.

It will be seen from the figures that the process takes place by a cleft appearing at the distal end (E^1) and gradually deepening until there are produced two complete and full-size individuals upon a single stalk (E^2). This state of things does not last long: one of the two daughter-cells takes on a nearly cylindrical form, keeps its disc and peristome retracted, and acquires a new circlet of cilia near its proximal end (E^3): it then detaches itself from the stalk, which it leaves in the sole possession of its sister-cell, and swims about freely for a time. Sooner or later it settles down, becomes attached by its proximal end, loses its basal circlet of cilia, and develops a stalk, which ultimately attains the normal length.

The object of this arrangement is obvious If, when a Vorticella divided, the plane of fission extended down the stalk until two ordinary fixed forms were produced side by side, the constant repetition of the process would so increase the numbers of the species in a given spot that the food-supply would inevitably run short. This is prevented by one of the two sister-cells produced

by fission leading a free existence long enough to enable it to emigrate and settle in a new locality, where the competition with its fellows will be less keen. The production of these free-swimming zooids is therefore a *means of dispersal:* contrivances having this object in view are a very general characteristic of fixed organisms.

Conjugation occasionally takes place, and presents certain peculiarities A Vorticella divides either into two unequal halves (F^2) or into two equal halves, one of which divides again into from two to eight daughter-cells (F^1). There are thus produced from one to eight *microzooids* which resemble the barrel-shaped form (E^3) in all but size, and like it become detached and swim freely by means of a basal circlet of cilia. After swimming about for a time, one of these microzooids comes in contact with an ordinary form or *macrozooid*, when it attaches itself to it near the proximal end (G^1), and undergoes gradual absorption (G^2), the macro- and micro-zooids becoming completely and permanently fused to form a *zygote* (p. 209).

Notice that in this case the conjugating bodies or gametes are not of equal size and similar character, but one which is conveniently distinguished as the *microgamete* (= microzooid) is relatively small and active, while the other or *macrogamete* (=macrozooid, or ordinary individual) is relatively large and passive. As we have seen in the case of the frog (pp. 206 and 208), this differentiation of the gametes is precisely what we get in the higher animals, and, in fact, in almost all organisms with two sexes: the microgamete being the male, the megagamete the female conjugating body (p. 209).

The result of conjugation is somewhat different in the two cases just studied: in Paramecium no zygote is

formed, conjugation being a mere temporary union (p. 263): in Vorticella the zygote is an actively moving and feeding body, indistinguishable from an ordinary individual of the species.

Vorticella sometimes encysts itself (Fig. 77, H^1), and the nucleus of the encysted cell has been observed to break up into a number of separate masses, each doubtless surrounded by a layer of protoplasm. After a time the cyst bursts, and a number of small bodies or *spores* (H^2) emerge from it, each containing one of the products of division of the nucleus. These acquire a circlet of cilia (H^3), by means of which they swim freely, and they are sometimes found to multiply by simple fission (H^4). Finally, they settle down (H^5) by the end at which the cilia are situated, the attached end begins to elongate into a stalk (H^6), this increases in length, the basal circlet of cilia is lost, and a ciliated peristome and disc are formed at the free end (H^7). In this way the ordinary form is assumed by a process of progressive differentiation or *development* (p. 10); and, moreover, the free-swimming young (H^3), to which the spores formed by division of the encysted protoplasm give rise, differ strikingly in form and habits from the adult. This is expressed by saying that development is in this case accompanied by a *metamorphosis*, this word, literally meaning simply a change, being always used in zoology to express a striking and fundamental difference in form and habit between the young and the adult; as, for instance, between the tadpole and the frog, or between the caterpillar and the butterfly. It is obvious that in the present instance metamorphosis is another means of ensuring dispersal.

In Vorticella, as we have seen, fission results not in the production of equal and similar daughter-cells, but of one stalked and one free-swimming form. It is, how-

ever, quite possible to conceive of a Vorticella-like organism in which the parent-cell divides into two equal and similar products, each retaining its connection with the stalk. If this process were repeated again and again, and if, further, the plane of fission were extended downwards so as to include the distal end of the stalk, the result would be a branched, tree-like stem with a Vorticella-like body at the end of every branch.

Colonial Forms.—As a matter of fact, this process takes place not in Vorticella itself, but in some nearly allied infusors, such as *Carchesium* and *Epistylis*. Each of these forms consists of a main stem attached by its proximal end and giving off at its distal end several branches, on each of which numerous bell-animalcules with short stalks are borne, like foxgloves or Canterbury bells on their stem.

We see, then, that Carchesium and Epistylis differ from all our previous types in being *compound organisms*. The entire "tree" is called a *colony* or *stock*, and each separate bell-animalcule borne thereon is an *individual* or *zooid*, morphologically equivalent to a single Vorticella or Paramecium. The colony is therefore an *individual of a higher grade* than the zooid; and such a multicellular animal as a frog, the cells of which differ markedly in structure and function, is an individual of a higher grade still.

As in Vorticella, the stem of Carchesium consists of a cuticular sheath with an axial muscle-fibre which, at the distal end of the main stem, branches like the stem itself, a prolongation of it being traceable to each zooid; so that the muscular system is common to the whole colony, and any shock causes a general contraction of all the zooids. The stalk of Epistylis, on the other hand, is non-contractile.

PRACTICAL DIRECTIONS.

Paramecium.—1. Spread a little cotton-wool on a slide over a drop of water containing Paramecia (see note on p. 254), in order to entangle them in its meshes, and put on a cover-glass. Examine first with the low power and then with the high power. Note—

a. The elongated form of the animal (Fig. 76); its anterior (more rounded) and posterior (more pointed) end; its flattened dorsal and ventral surfaces; and its *mouth*, near the middle of the ventral surface.

b. The active movements, due to the *cilia* covering the body.

c. The marked distinction between *cortical* and *medullary* portions.

d. The characters of the elastic *cortical portion*:—(*a*) the superficial *cuticle*, and deeper striated layer; (*b*) the *cilia* arising from the deeper layer, and projecting through the cuticle; (*c*) the *trichocysts*—small oval sacs, imbedded in the deeper layer; (*d*) the two spherical *contractile vacuoles*, in close relation with the deeper layer on the dorsal side: note that canals radiate from them when they contract; (*e*) the cilia lining the buccal groove. (The potential *anus* behind the mouth can only be seen at the moment of defæcation.) Compare the mode of feeding with that of Amœba.

e. The characters of the *medullary portion*:—(*a*) the *food-vacuoles* and their circulation; (*b*) the *macronucleus* and *micronucleus*, which can be better seen when stained. Sketch.

2. The movements of Paramecium can be slowed by adding on the slide, to the drop of water containing the animals, a drop of mucilage obtained by soaking *Ispaghul* seeds (seeds of *Plantago ovata*) in water; or better still if in a tube seeds are spread 1—2 cm. high, and 5—8 cm. of culture containing Paramecia poured over it, the mucilage will dissolve into the culture, and in about twenty-four hours all the Paramecia will have collected in the lower part of the fluid, *i.e.*, on the free upper surface of the column formed by the swollen seeds; that is to say, they will have collected in that part where the thickness of the slimy stuff diffused is greatest and consequently locomotion of the animals least permitted. If a drop is taken from such a culture, the animals can be very satisfactorily examined, as they do not move about rapidly.

3. If it is desired to kill Paramecia, the slide on which there is a drop of water containing the animals is inverted

over the mouth of a bottle containing 1 per cent. osmic acid solution for some seconds, when they are killed instantly by the vapour Another method of killing them is to pour a little hot corrosive sublimate (saturated aqueous solution) over the drop.

4. Add acetic methyl-green or iodine-green. Then note again the structure of cortical and medullary portions, as well as—(*a*) the oval *macronucleus*, near the middle of the body; (*b*) the *micronucleus*, a smaller body, close to the meganucleus; (*c*) the extruded *trichocysts*. Sketch.

5. Look out for specimens undergoing transverse *fission*, and also for others in process of *conjugation*. Sketch.

Permanent preparations may be made as directed in the case of Amœba (p 255).

Vorticella.—Mount some specimens in a drop of water, and examine with the low power. The Vorticella will be seen to have the form of a wine-glass or bell with a long stem. The stem frequently contracts spirally, the edge of the bell being at the same time turned in, so as to give the animal a rounded form. Put on the high power and note—

1. The form of the bell (Fig. 77), its thickened rim or *peristome*, and the *disc*, which forms a cover to the bell.

2. The *mouth* and *gullet*, opening on one side between the peristome and disc, which is here slightly raised. (The *anal spot* is in the oral depression, but can only be seen at the moment of defæcation)

3. The *single row of cilia* round the peristome and extending down the gullet on the one hand, and on to the raised portion of the disc on the other. Run in a little finely powdered indigo or carmine under the cover-glass, and note the currents produced by the cilia: the granules of pigment will be carried down the gullet.

4. The *contractions* of the bell and stalk.

5. The structure of the *cortical portion*, which is similar to that of Paramecium, except that the cilia have a restricted distribution, and there are no trichocysts. Moreover, in the stalk (into which the medulla does not extend) the deeper layer of the cortex gives rise to a central *contractile axial fibre*, by means of which the stalk can contract spirally. The *contractile vacuole* is single.

6. The *medullary portion*, which circulates and contains *food-vacuoles*, as in Paramecium. In it are situated an elongated and curved *macronucleus*, and a minute *micronucleus* which is not easy to distinguish. Sketch.

7. Make preparations as directed under Paramecium. Sketch.

8. Look out for specimens undergoing *fission*, noting the different stages, and the second, proximal ring of cilia on *one* of the daughter individuals, which eventually becomes detached. Note these *free-swimming forms*, and also search for *conjugating* individuals—a small free Vorticella uniting with a large stationary one Sketch.

Carchesium or Epistylis.—You will very likely find specimens of one of these, or of an allied genus, amongst the Vorticellæ. Note that several individual *zooids* are borne upon a branched stalk, together forming a *colony*.

CHAPTER III

PARASITISM—MALARIAL PARASITES—CLASSIFICATION OF THE UNICELLULAR ORGANISMS EXAMINED

Parasitism.—Amongst the Protozoa (see p. 234) are found certain forms which are *parasites*. Parasites are organisms which live in association with other organisms, the ready digested food of which they utilise, or even nourish themselves from the tissues of the forms they infest. It will be interesting to compare Paramecium with a ciliate infusor which lives in the intestine of *Rana tigrina*, and is known as *Opalina coracoidea*.[1]

Opalina has a flattened body with an oval outline, and full-sized specimens may be as much as 1 mm. in length. The protoplasm is divided into cortex and medulla, and is covered with a cuticle; the cilia are equal-sized and uniformly arranged in longitudinal rows over the whole surface.

On a first examination no nucleus is apparent, but after staining, a large number of globular nuclei can be seen; these nuclei multiply within the body of the infusor.

There is no contractile vacuole, and no trace of either mouth or gullet, so that the ingestion of solid food is impossible. The creature lives, as already stated, in the intestine of the frog: it is therefore an *internal*

[1] Certain other parasitic ciliates, *e.g.*, *Nyctotherus* and *Balantidium*, are also commonly found in the rectum of *Rana tigrina*.

parasite, or *endoparasite*, having the frog as its *host*. The intestine contains the partially-digested food of the frog, and it is by the absorption of this that the Opalina is nourished. Having no mouth it feeds solely by imbibition: it simply absorbs food ready digested by its host, upon which it is dependent for a constant supply of soluble and diffusible nutriment.

In another group of the Protozoa known as the *Sporozoa* parasitism occurs without exception, and the relation between parasites and host is much more intimate than in the case of Opalina: instead of living within the enteric canal and merely absorbing the contained products of digestion, these penetrate into the tissues of the host, even passing into the interior of its cells, from the contents of which they absorb fluid nutriment. As is the rule in parasites, they are able to multiply very rapidly.

Sporozoan parasites occur in most classes of animals: many seem to be comparatively innocuous, so that even when infested with large numbers the host apparently suffers no harm. In other cases they, like some other parasitic Protozoa (*e.g.*, the flagellate *Trypanosoma* in "sleeping sickness") and certain Bacteria, may cause dangerous diseases and epidemics. One of the dangerous and extremely widespread diseases is malaria, from which in India alone millions of people die every year; and millions more who escape death are weakened and injured by this disease. The symptoms of the disease are unfortunately too well known to need any description. Practically everyone in this country has had an attack of malarial fever, and has experienced for himself the chill and the shaking of the body which mark the onset of the attack, the rise of temperature (fever), which is succeeded by the sweating stage, in which the body perspires freely, the temperature comes down to the

normal, and the person is apparently healthy, but subject to subsequent attacks, unless remedial measures are adopted. The disease came to be called malaria, as it was formerly supposed to be due to the effect of bad air (Italian *malo*, bad; *aria*, air) in marshy districts or other places where collections of stagnant water abound after the rains. But it is now definitely known to be due to the existence of a Protozoan parasite in the blood.

Malarial Parasite.—This parasite has two hosts, viz., man and mosquito. In man, the parasite lives in the red blood-corpuscles. There are several types of malarial fever, and these are probably due to different species of the parasite. Three chief forms are generally recognised: *Plasmodium vivax*, found in tertian fever, the attacks of which recur every other day, *Plasmodium malariæ*, found in quartan fever, and *Plasmodium falciparum* (also known as *Laverania malariæ*), which causes malignant tertian or sometimes an irregular or quotidian fever. The three differ from each other in certain structural details and the time they take to complete their asexual reproduction, but otherwise the life-histories are quite similar.

Schizogony.—A certain number of minute parasites, in a condition in which they are known as *sporozoites*, are introduced into human blood by the bite of a mosquito of the genus *Anopheles*. The sporozoites are slender curved bodies, pointed at either end and with a thicker central portion containing the nucleus. Each sporozoite makes its way into a red blood-corpuscle, and once within the corpuscle it becomes rounded and grows at the expense of the corpuscle. In the early stages, each has a large space in its body, probably caused by a vacuole which gives it a signet-ring appearance (Fig. 78, 3) in fixed and stained preparations. As the parasite grows, the ring-like form is less evident; it becomes more compact and amœboid, and is known

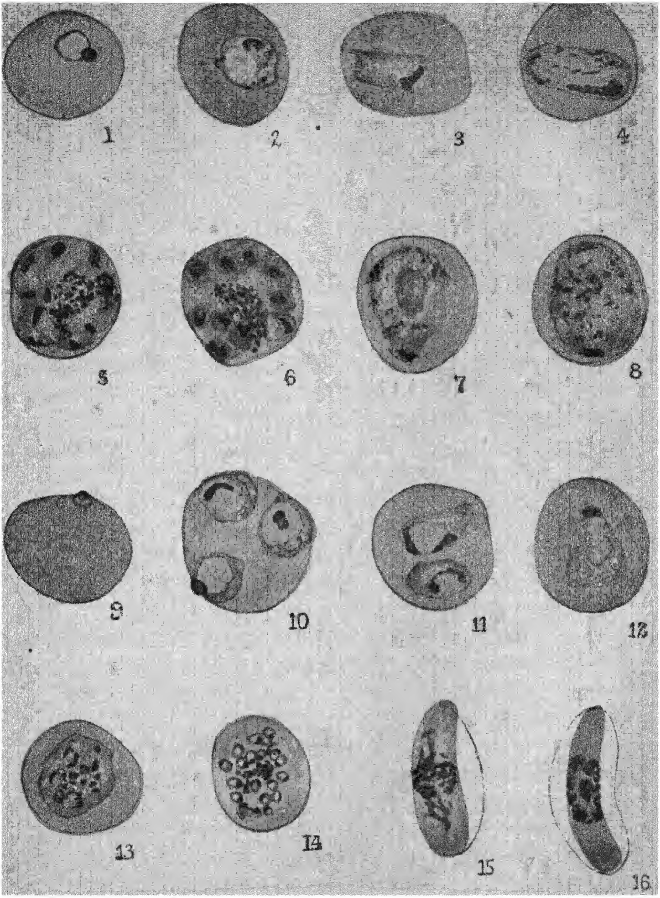

Plate Figs 1–8 Stages in the life-cycle of the organism of quartan malaria, *Plasmodium malariae* Figs 9–16 Stages in the life-cycle of the organism of malignant tertian malaria, *Plasmodium falciparum* In the blood of man as stained with Wright's stain (From Hegner and Taliaferro's *Human Protozoology*)

P malariae —1, Trophozoite in the ring stage, 2, older trophozoite, 3, schizont, 4, older schizont, 5, stage prior to segmentation, ten merozoites are being formed and the pigment is aggregated in the centre, 6, merozoites completely formed, 7, microgametocyte, 8, macrogametocyte

P falciparum —9, Trophozoite in ring stage, note small size and position of the parasite near the edge of the corpuscle, with chromatin dot extended over the edge, 10, triple infection of one red corpuscle with three young schizonts, 11, double infection of one cell with older schizonts, 12, old schizont, 13, stage prior to segmentation, 14, merozoites fully formed, 15, microgametocyte, crescent shaped, comparatively thicker and with more diffuse chromatin, 16, macrogametocyte, crescent shaped, comparatively thinner, and with more compact chromatin

as the *trophozoite*. When full-grown, the trophozoite is spherical and almost as large as the corpuscle and proceeds to divide by a process of multiple fission known as *schizogony*. The nucleus divides into a number of nuclei which come to the surface, and the protoplasm constricts round these daughter nuclei to form a rosette (Fig. 78, 6) of smaller parasites called *merozoites* surrounding the residual unused part of the schizont which contains all the pigment granules. The enfeebled blood-corpuscle can resist no longer and breaks up, and the merozoites are set free into the blood-stream. These enter as many uninfected corpuscles, develop into trophozoites, become schizonts, and repeat the rosette-formation. The generic name *Plasmodium* given to these parasites is a very inappropriate one, as in no phase of their life-cycle do they become what is ordinarily understood in zoology by the term plasmodium (a multinucleate mass of protoplasm formed by a number of amœboid organisms coalescing together). Owing to the characteristic amœboid phase, the parasites are generally referred to as Hæmamœbæ (*haima*, blood), but it is unfortunate that the name plasmodium cannot be replaced by a more appropriate one. When first introduced, the number of parasites is small and no inconvenience is caused to the host (the man harbouring them in his blood). For about ten days this schizogonous multiplication goes on, till the number of infected corpuscles becomes so large that, on their breaking up, toxic products are set free in the blood which cause an attack of fever. This period which elapses between the first introduction of the parasites into blood by the bite of a mosquito and their multiplication to such a degree as to be able to make their existence felt by the host and to cause the disease in him is called the incubation period. After the first attack of fever, there are succes-

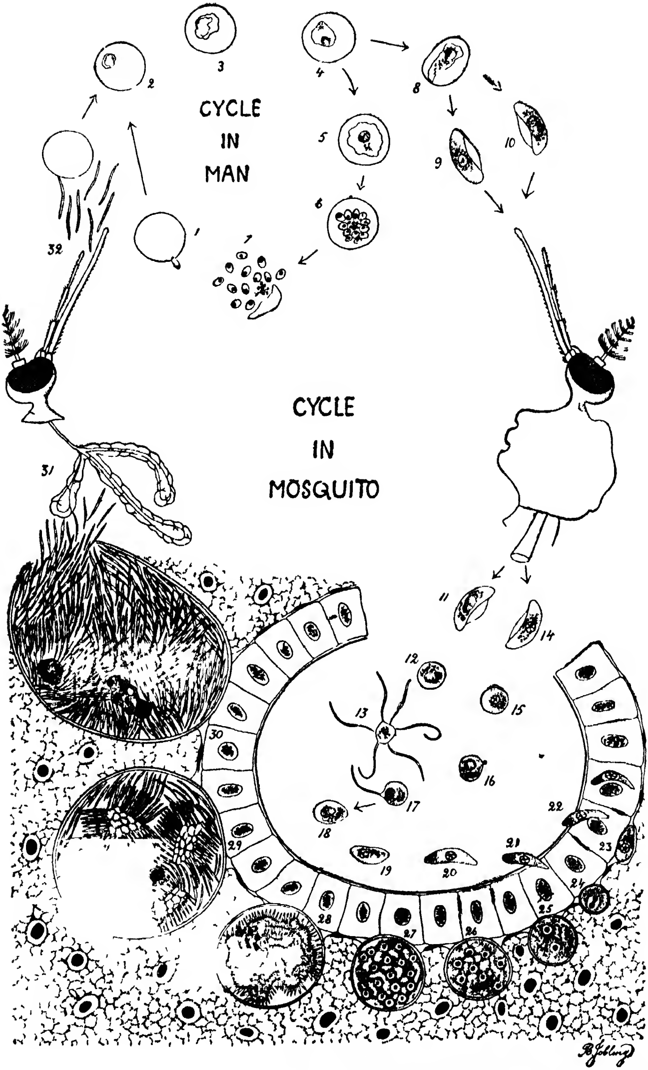

FIG 78.—Life-cycle of Malarial Parasite, *Plasmodium falciparum* in Man and the Mosquito. (After Wenyon)

sive attacks at each period of merozoite formation. The period for a schizogonous cycle for *P. vivax* is forty-eight hours, and for *P. malariæ* seventy-two hours, and relapses occur every other day in the case of "tertian" and every third day in the case of "quartan" fever. By repeated schizogony the number of parasites increases in a geometrical progression until a very large number of corpuscles are destroyed, the only natural check being the action of the leucocytes which destroy the merozoites. The well-known drug quinine also destroys the merozoites when they escape from the corpuscles and before they have safely ensconced themselves inside other corpuscles.

Conjugation.—After a number of asexual generations, some of the trophozoites develop into gametocytes, that is, cells which will give rise to gametes. In *P. falciparum* the gametocytes are elongated oval and slightly curved bodies, exceeding in length the diameter of the corpuscle, the remains of which are seen in the hollow of the gametocytes (Fig. 78, 9 and 10). These are familiarly known as "crescents" and are characteristic of pernicious malaria. The male progenitors or microgametocytes have a larger nucleus and lightly staining cytoplasm, while the female progenitors, or macrogametocytes, have a smaller nucleus and dark staining cytoplasm. The crescents appear to originate in the spleen and bone-marrow, but when fully developed are found in the superficial blood-vessels. Having freed themselves from the remains of blood-corpuscles, they become oval and afterwards spherical. They do not get beyond the spherical stage in the human blood, and may be transferred to the stomach of the mosquito as crescents, ovals, or spheres. Unless these sexual forms are taken in by a mosquito they perish. If an anopheline

mosquito sucks the blood of a malarious patient the gametocytes persist and develop further. Should a gnat (*Culex*) suck infected human blood, the parasites in all their forms get digested.

The further development of the gametocytes and the process of conjugation take place in the stomach of the mosquito. In the male gametocyte the nucleus divides rapidly into four to six parts, which move to the surface of the parent cell. Then suddenly and with explosive violence the nuclei elongate and with a small quantity of protoplasm form long, slender, motile bodies, the microgametes (Fig. 78, 13). These microgametes move rapidly here and there, till they reach the female gamete. In the macrogametocyte the nucleus remains undivided, but gives off a small portion of its chromatin. The macrogametocyte thus gives rise to a single female gamete, which forms a small superficial protuberance or cone of attraction to receive one of the microgametes (Fig. 78, 16). After the latter has entered into the substance of the macrogamete, its chromatin is seen to form a male pronucleus. The two pronuclei now unite and as the result of the conjugation of two gametes a zygote is formed (Fig. 78, 17, 18).

Sporogony.—The zygote becomes elongated and shows extraordinary activity. It moves actively over the inner surface of the stomach and on account of its worm-like, gliding movements is designated a vermicule or *ookinete*. Gradually it bores its way through the epithelium of the stomach, and reaching the tissue outside the epithelium becomes rounded and motionless, and secretes a cyst, but continues to grow in size. These cysts are seen forming small rounded projections on the external surface of the stomach of an infected mosquito (Fig. 79). The nucleus of the encysted zygote begins to divide, and division is repeated a great number of

times. The cytoplasm develops vacuoles, till it becomes a sponge-like mass (Fig. 78, 26 and 27). The minute nuclei pass to the surface, and in this way the cytoplasm becomes studded with protrusions. These take the form of slender, sickle-shaped bodies, which when fully developed separate from the mass within (Fig. 78, 29).

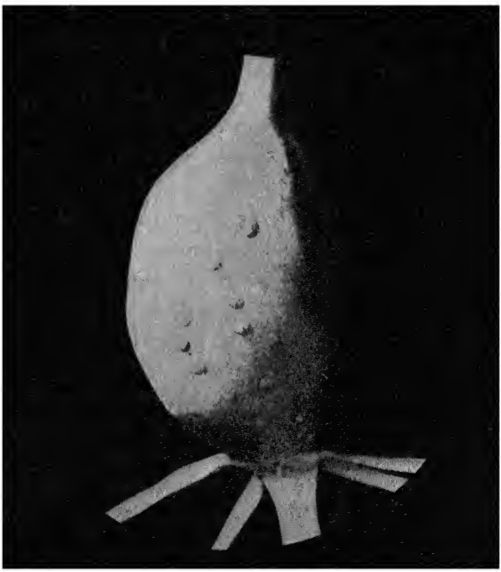

Fig. 79—Stomach of an infected mosquito

Each tiny body so formed is called a *sporozoite*, and the cyst may contain thousands of these small sporozoites, together with the rest of the cytoplasm and, in addition, a blackish pigment (melanin). Ultimately, the cyst bursts and liberates the contained sporozoites into the body-cavity of the mosquito. The sporozoites travel

in the body-fluids until they reach the salivary glands. The mosquito is now infective. Only the female mosquito sucks blood, as blood is required by it to furnish energy for propagation. When a female mosquito with sporozoites in its salivary glands pierces the skin of a human being, it injects into the puncture a drop of saliva containing numbers of sporozoites. Thus the mosquito not only sucks blood, but also spits into the wound, and to add injury to this insult further introduces the sporozoites of the malarial parasites. It takes about ten days for the cycle to be completed in the mosquito.

It will have been seen from the foregoing account of the life-history of the malarial parasite that it lives in the body of two hosts, first man, in whose blood it multiplies by schizogony, and secondly the mosquito, in whose body sexual forms are differentiated and conjugation is followed by sporogony. Of these two hosts, man is the intermediate host, and the mosquito the final or definitive host, since it is in this latter that the parasite undergoes sexual differentiation. At no period of its life does the parasite have a free existence. From mosquito to man and man to mosquito goes on the cycle.

History of the Discovery.—The complicated life-history of the parasite has been fully worked out through the combined labours of a large number of distinguished workers. In 1880, Laveran, a French army surgeon, discovered the parasites while examining the blood of a malarial patient. Further search proved that these were always to be found in the blood of persons suffering from malaria, and the discovery of the parasites was confirmed by Golgi and other workers. Sir Patrick Manson had previously found the embryos of a parasitic worm known as *Filaria* in the tissues of the mosquito. So he made the suggestion that possibly in malaria also the parasites are introduced into the

human body by the bite of a mosquito. Following his suggestion, Sir Ronald Ross (then Major in the Indian Medical Service, working at Secunderabad in Southern India) fed all the different kinds of mosquito procurable on blood of malarial patients, and then dissected and examined every part of their bodies to see if there was any trace of the parasites. Hundreds of mosquitoes were examined, but for two years (1895–97) no clue could be obtained. In 1897 he discovered pigmented cysts on the stomach of an Anopheline mosquito which had been fed on human blood containing crescents, and a year later, working with bird malaria, succeeded in elucidating the life cycle of those parasites in Culex mosquitoes. The same year (1898) Grassi and his co-workers studied the complete development of the human parasite in an Anopheline mosquito, and they also succeeded in infecting a man with malaria by means of Anopheline mosquitoes. Manson (1900) also succeeded in infecting a man in London with malaria by means of anopheles imported from Italy. Last of all, to demonstrate that a bite from infected mosquitoes was the only source of infection, a party of two medical men with two other companions went and lived for four months in mosquito-proof houses in one of the most malarious districts in Italy and did not catch the infection, while practically every one in the neighbourhood was getting it.

Prevention of Malaria.—The problem of effectively dealing with malaria is a great national problem in India, and the student who has acquainted himself with the life-cycle of the malarial parasite should feel interested to know the general principles on which all preventive measures are based. These are :—

(1) To kill the mosquitoes in all stages of their development (Chapter VI).

(2) To save ourselves from being bitten by the mosquitoes.

(3) To destroy the malarial parasites existing in the blood or other parts of the body of persons suffering from the disease.

(4) To kill the parasites that may happen to find their way into the blood of healthy individuals and thus prevent their subsequent development and multiplication.

Classification.—Each of the organisms which we have studied in this and the two previous chapters consists of a single cell—or in the case of Carchesium and Epistylis of a colony of cells to a large extent independent of one another. They are therefore placed in the lowest primary division of the animal kingdom—the phylum **Protozoa** (p. 234). This phylum is subdivided into a number of *classes*, examples of certain of which we have examined.

Class **Sarcodina.** Protozoa devoid of cuticle and possessing pseudopodia. Amœboid form predominant. *Amœba.*

Class **Flagellata.** Protozoa covered with a cuticle and possessing one or more whip-like processes, called flagella. *Euglena.*

Class **Ciliophora.** Protozoa covered with a cuticle and possessing cilia.

Those wholly covered with cilia. *Paramœcium, Opalina.*

Those with a single band of cilia. *Vorticella, Carchesium,* etc.

Class **Sporozoa.** Endoparasitic Protozoa devoid of cilia or flagella, in which spore-formation is the usual mode of reproduction. *Plasmodium.*

The animals above the Protozoa are placed, as we have seen, in a number of different phyla, but as they

are all multicellular they are often spoken of collectively as the **Metazoa,** one of the simplest of which we must next examine.

PRACTICAL DIRECTIONS

Malarial Parasites.—A few prepared slides are put as demonstration specimens under microscopes provided with 1/12 oil immersion objectives. Look in the red corpuscles for the presence of small black specks. These are surrounded by clear areas In the centre of some of the red cells you will find clear amœboid areas which show no pigment. Rosette forms may also be visible. In the slide marked "malignant tertian," look for "crescents," which will be found to be rather longer than the corpuscles containing them. Sketch these forms

Preparation and staining of blood films.—The following hints are given for the use of the demonstrators and more advanced students to enable them to prepare slides for demonstration purposes :—

How to make films —Prick the finger and apply one end of a slide to a drop of blood; place the slide on the table, holding it in position with the thumb and index finger of the left hand. Place the narrow edge of a second slide in the drop and hold it there till the blood has spread across it, and then draw it slowly over the whole length of the first slide. The second slide should be inclined to the first at an angle of 45°, and there should be no pressure whatever between the two surfaces The more slowly one slide is drawn over the other the thinner is the resulting film. After the blood is spread, let the film dry by waving the slide rapidly in the air.

Fixation of the film.—Films may be fixed, after drying, by immersing in absolute alcohol for fifteen minutes. Fixation is, however, provided for in staining by Leishman's method, as the stains are dissolved in absolute alcohol.

How to stain the film.—Blood films are generally stained by any of the modifications of Romanowsky stains, which

depend for their action on the compounds formed by the interaction of methylene-blue and eosin. Leishman's stain is dissolved in pure methyl alcohol in the proportion of 0·5 per cent. and used as follows :—

Cover the dry film well over with the stain, which should be evenly distributed over the entire slide At the end of one minute, carefully add double the quantity of distilled water and mix with the stain by means of a clean glass pipette. At the end of seven minutes pour off the mixture, and cover the film with distilled water for two minutes. Pour this off and wash again with distilled water, and dry the film gently with clean blotting-paper.

Stained as above, the red blood-corpuscles are coloured pink, the nuclei of the white blood-corpuscles a reddish-purple, and the granules inside the white corpuscles pink and blue respectively, according as they are acidophil or basophil. The nuclear substance of the malarial parasite is stained a reddish-purple.

CHAPTER IV

HYDRA: OBELIA—SYMBIOSIS—ALTERNATION OF GENERATIONS—CHARACTERS OF THE PHYLUM CŒLENTERATA—CLASSIFICATION

Hydra.—A careful search in ponds will often result in the capture of some small organisms known as "fresh-water polypes," belonging to the genus *Hydra*.

Although far from uncommon in pond-water, Hydra is not always easy to find, being rarely abundant and by no means conspicuous. In looking for it the best plan is to fill either a clear glass bottle or jar, or a dish, with pieces of floating or submerged twigs, weeds, and water from a pond, and to let it remain undisturbed for a short time. If the gathering is successful there will be seen adhering to the sides of the glass, or the bottom of the dish, or pieces of twigs or the weeds, little white, tawny bodies, about as thick as fine sewing-cotton, and up to 12 mm. in length. They adhere pretty firmly by one end, and examination with a pocket lens shows that from the free extremity a number of very delicate filaments, barely visible to the naked eye, are given off.

External Features.—Under the low power of a compound microscope a Hydra (Fig. 80) is seen to have a cylindrical body attached by a flattened base to a weed or other aquatic object, and bearing at its opposite or distal end a conical structure, the *hypostome* (*hyp*), at the apex of which is a circular aperture, the mouth (*mth*).

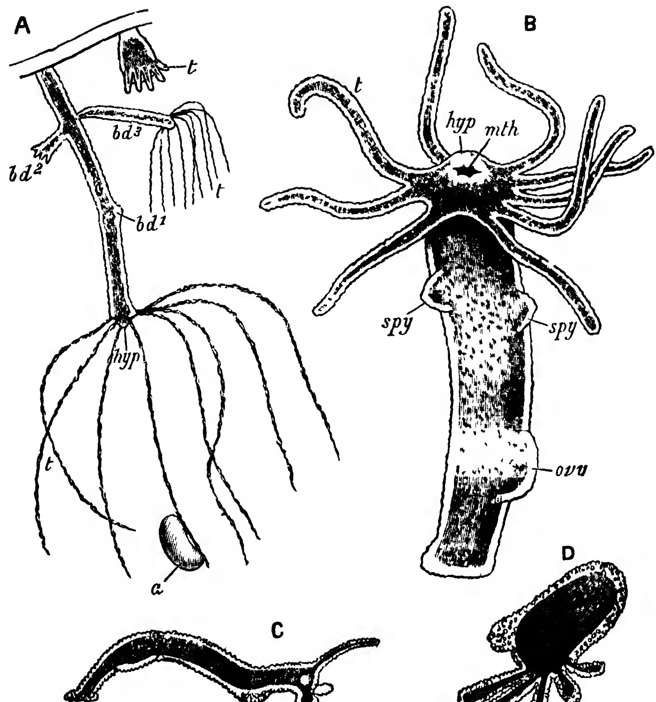

FIG 80 —*Hydra*

A, two living specimens of *H viridis* attached to a bit of weed The larger specimen is fully expanded, and shows the elongated body ending distally in the hypostome (*hyp*), surrounded by tentacles (*t*), and three buds (*bd*1 *bd*2, *bd*3) in different stages of development, a small water-flea (*a*) has been captured by one tentacle. The smaller specimen (to the right and above) is in a state of complete retraction, the tentacles (*t*) appearing like papillæ (× 6)
B, *H fusca*, showing the mouth (*mth*) at the end of the hypostome (*hyp*), the circlet of tentacles (*t*), two spermaries (*spy*), and an ovary (*ovy*) (× 12)
C, a Hydra creeping on a flat surface by looping movements
D, a specimen crawling on its tentacles. (From Parker's *Biology:* C and D after W. Marshall)

At the junction of the hypostome with the body proper are given off usually from four to six, occasionally eight, long delicate *tentacles* (*t*) arranged in a circlet or whorl.

A longitudinal section shows that the body is hollow, containing a spacious cavity, the *enteron* (Fig. 82, A, *ent. cav*), which communicates with the surrounding water by the mouth. The tentacles are also hollow, their cavities communicating with the enteron.

Thus it will be seen that the Hydra is not *bilaterally symmetrical*, like the frog—*i.e.*, equally divisible into two lateral halves by a median vertical plane passing through the axis of the body—but is *radially symmetrical*, *i.e.*, the body is divisible into similar parts radiating from a common central axis.

Three well-established species of Hydra are generally recognised: one, *H. vulgaris*, is colourless or nearly so and is found in all parts of India; another, *H. fusca*, is of a pinkish-yellow or brown colour and occurs in certain parts of India; and the third, *H. viridis*, which is of a bright green colour, has not so far been found anywhere in India. In the two latter the colour is in the inner parts of the body-wall, the outside of which is formed by a transparent, colourless layer (Fig. 82). In *H. vulgaris* (Fig. 81) the tentacles are slender, and when the animal is at rest not much longer than the body. They are, however, capable of very great extension, and in the fully extended condition look like very fine wires with minute beads (groups of nematocysts) strung upon them.

An examination of the living animal shows, in the first place, that its form is continually changing. At one time (Fig. 80, A, left-hand figure) it extends itself until its length is fully fifteen times its diameter and the tentacles appear like long delicate filaments: at another time (right-hand figure) it contracts itself into an almost globular mass, the tentacles then appearing like little blunt knobs.

Besides these movements of contraction and expansion, Hydra is able to move slowly from place to place.

This it usually does after the manner of a looping caterpillar (C): the body is bent round until the distal end touches the surface: then the base is detached and moved nearer the distal end, which is again moved forward, and so on. It has also been observed to crawl like a cuttle-fish (D) by means of its tentacles, the body being kept nearly vertical.

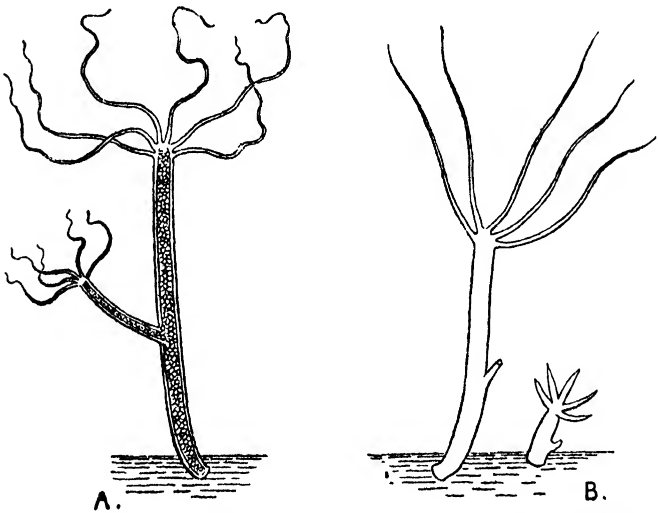

FIG. 81.—*Hydra vulgaris.* A, winter brood; B, summer brood; the same individual in an expanded and contracted condition. B is more highly magnified than A. (After Annandale.) *Reproduced by permission from "Fauna of British India."*

It is also possible to watch a Hydra feed. It is a very voracious creature, and to see it catch and devour its prey is a curious and interesting sight. In the water in which it lives are always to be found numbers of "water-fleas," minute animals of about a millimetre or less in length, belonging to the class *Crustacea* (see Chapter VI).

Water-fleas swim very rapidly, and occasionally one

may be seen to come in contact with a Hydra's tentacle. Instantly its hitherto active movements stop dead, and it remains adhering in an apparently mysterious manner to the tentacle. If the Hydra is not hungry it usually liberates its prey after a time, and the water-flea may then be seen to drop through the water like a stone for a short distance, but finally to expand its limbs and swim off. If, however, the Hydra has not eaten recently, it gradually contracts the tentacles until the prey is brought near the mouth, the other tentacles being also used to aid in the process. The water-flea is thus forced against the apex of the hypostome, the mouth expands widely and seizes it, and it is finally passed down into the digestive cavity. Hydræ can often be seen with their bodies bulged out in one or more places by recently swallowed water-fleas.

Structure.—The precise structure of Hydra is best made out by cutting it into a series of extremely thin sections and examining them under a high power of the microscope. The appearance presented by a vertical section through the long axis of the body is shown in Fig. 82, A.

The whole animal is seen to be built up of cells, each consisting of protoplasm with a large nucleus (B–D, *nu*), and with or without vacuoles. As in the case of most animal cells, there is no cell-wall.

The essential feature in the arrangement of the cells is that they are disposed in two layers round the central digestive cavity or enteron (A, *ent. cav*) and the cavities of the tentacles (*ent. cav'*). So that the wall of the body is formed throughout of an outer layer of cells, the *ectoderm* (*ect*), and of an inner layer, the *endoderm* (*end*), which bounds the enteric cavity (compare p. 213). Between the two layers is a delicate transparent membrane, the *mesoglœa*, or *supporting lamella* (*msgl*). A

transverse section (B) shows that the cells in both layers are arranged radially.

Thus Hydra is a two-layered or *diploblastic* animal, and may be compared to a chimney built of two layers of radially arranged bricks with a space between the layers filled with mortar or concrete.

Accurate examination of thin sections, and of specimens teased out or torn into minute fragments with needles, shows that the structure is really much more complicated than the foregoing brief description would indicate.

The ectoderm-cells are of two kinds. The first and most obvious (B, *ect*, and C) are large cells of a conical form, the bases of the cones being external, their apices internal. Spaces are necessarily left between their inner or narrow ends, and these are filled up with the second kind of cells (*int. c*), small rounded bodies which lie closely packed between their larger companions and are distinguished as *interstitial cells*.

The inner ends of the large ectoderm-cells are continued into narrow, pointed prolongations (C, *m. pr*) placed at right angles to the cells themselves and parallel to the long axis of the body. There is thus a layer of these longitudinally-arranged *muscle-processes* lying immediately external to the mesoglœa (B, *m. pr*). They appear to possess, like the axial fibre of Vorticella (p. 267), a high degree of contractility, the almost instantaneous shortening of the body being due, in great measure at least, to their rapid and simultaneous contraction. It is probably correct to say that, while the ectoderm-cells are both contractile and irritable a special degree of contractility is assigned to the muscle-processes, the cells themselves being eminently irritable, the slightest stimulus applied to them usually being followed by immediate contraction of the whole body.

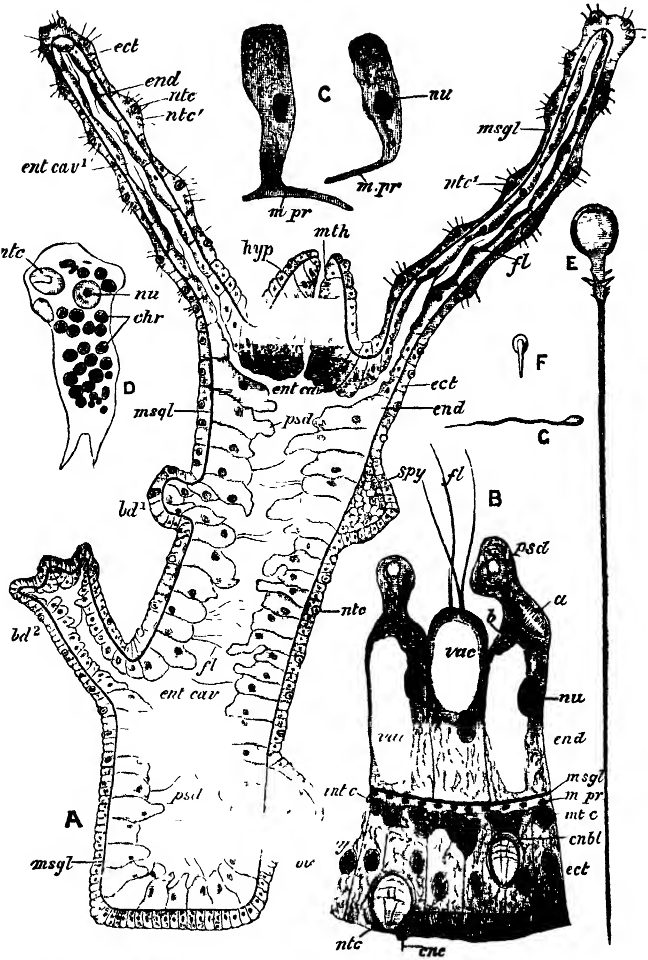

FIG. 82.—*Hydra*.

A, vertical section of the entire animal, showing the body-wall composed of ectoderm (*ect*) and endoderm (*end*), enclosing an enteric cavity (*ent cav*), which, as well as the two layers, is continued (*ent cav*) into the tentacles, and opens externally by the mouth (*mth*) at the apex of the hypostome (*hy*). Between the ectoderm and endoderm is the mesoglœa (*msgl*), represented by a black line.

In the ectoderm are seen large (*ntc*) and small (*ntc'*) nematocysts; some of the endoderm-cells are putting out pseudopods (*psd*), others flagella (*fl*). Two buds (*bd* 1, *bd* 2) in different stages of development are shown on the left side, and on the right a spermary (*spy*) and an ovary (*ovy*) containing a single ovum (*ov*). (× 20)

B, portion of a transverse section more highly magnified, showing the large ectoderm-cells (*ect*) and interstitial cells (*int c*); two cnidoblasts (*cnbl*) enclosing nematocysts (*ntc*) and one of them produced into a cnidocil (*cnc*); the layer of muscle-processes (*m pr*) cut across just external to the mesoglœa (*msgl*); endoderm-cells (*end*) with large vacuoles and nuclei (*nu*), pseudopods (*psd*), and flagella (*fl*) The endoderm-cell to the right has ingested a diatom (*a*), and all enclose minute black granules (× 100)

C, two of the large ectoderm-cells, showing nucleus (*nu*) and muscle-process (*m pr*).

D, an endoderm-cell of *H. viridis*, showing nucleus (*nu*), numerous Zoochlorellæ (*chr*), and an ingested nematocyst (*ntc*).

E, one of the larger nematocysts with extruded thread, barbed at the base.

F, one of the smaller nematocysts

G, a single sperm (From Parker's *Biology:* D after Lankester, F and G after Howes)

Imbedded in and between some of the large ectoderm-cells are found clear, oval sacs (*ntc*), with very well defined walls, called "*thread-cells*" or *nematocysts*. Both in the living specimen and in sections they ordinarily present the appearance shown in Figs. 82, B, and 83, A, but are frequently met with in the condition shown in Figs. 82, E, and 83, B, that is, with a short, conical tube protruding from the mouth of the sac, armed near its distal end with three recurved barbs besides several similar processes of smaller size, and giving rise distally to a long, delicate, flexible filament.

Accurate examination of the nematocysts shows that the structure of these curious bodies is as follows. Each consists of a tough sac (Fig. 83, A), one end of which is turned in as a hollow pouch: the free end of the latter is continued into a hollow, coiled filament, and from its inner surface project the barbs. The whole space between the wall of the sac and the contained pouch and thread is tensely filled with fluid. When pressure is brought to bear on the outside of the sac the whole apparatus goes off like a harpoon-gun (B), the compression of the fluid forcing out first the barbed pouch and then the filament, until finally both are turned inside out.

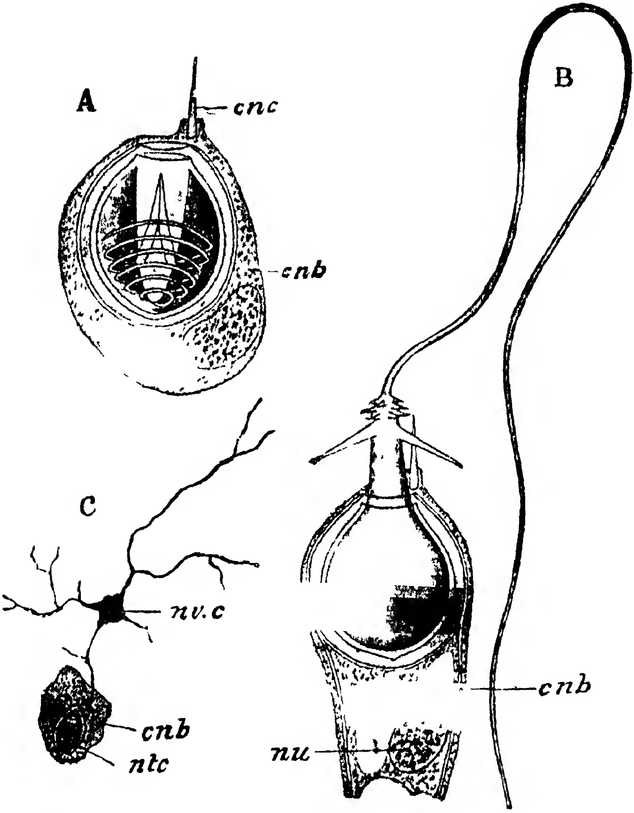

FIG 83 —*Hydra*
A, a nematocyst contained in its cnidoblast (*cnb*), showing its coiled filament and the cnidocil (*cnc*) (× 400)
B, the same after extrusion of the thread, showing the larger and smaller barbs at the base of the thread, *nu* the nucleus of the cnidoblast
C, a cnidoblast, with its contained nematocyst, connected with one of the processes of a nerve-cell (*nv c*). (From Parker's *Biology*; after Schneider)

It is by means of the nematocysts—the resemblance of which to the trichocysts of Paramœcium (p. 262) should be noted—that the Hydra is enabled to paralyse

its prey. Probably some specific poison is formed and ejected into the wound with the thread: in the larger members of the group to which Hydra belongs, such as jelly-fishes, the nematocysts produce an effect on the human skin quite like the sting of a nettle.

The nematocysts are formed in special interstitial cells called *cnidoblasts* (Figs. 82, B, and 83, *cnb*), and are thus in the first instance at a distance from the surface. But the cnidoblasts migrate outwards, and so come to lie quite superficially either in or between the large ectoderm-cells. On its free surface the cnidoblast is produced into a delicate pointed process, the *cnidocil* or "trigger-hair" (*cnc*). In all probability the slightest touch of the cnidocil causes contraction of the cnidoblast, and the nematocyst, thus compressed, instantly explodes.

Nematocysts are found in the distal part of the body, but are absent from the foot or proximal end, where also there are no interstitial cells. They are especially abundant in the tentacles, on the knob-like elevations of which—due to little heaps of interstitial cells—they are found in great numbers. Amongst these occur small nematocysts with short threads and devoid of barbs (Fig. 82, A, *ntc'*, and F).

In connection with the cnidoblasts small irregular cells with large nuclei occur (Fig. 83, C, *nv. c*); they are supposed to be *nerve-cells*, and to constitute a rudimentary *nervous system* (compare p. 177).

The ectoderm-cells of the foot differ from those of the rest of the body in being very granular (Fig. 82, A). The granules are probably the material of the adhesive secretion by which the Hydra fixes itself, and these cells are therefore *glandular* (p. 138).

The endoderm consists for the most part of large cells which exceed in size those of the ectoderm, and are

remarkable for containing one or more vacuoles, sometimes so large as to reduce the protoplasm to a thin superficial layer containing the nucleus (Fig. 82, A and B, *end*). Then, again, their form is extremely variable, their free or inner ends undergoing continual changes of form. This can be easily made out by cutting transverse sections of a living Hydra, when the endoderm-cells are seen to send out long blunt pseudopods (*psd*) into the digestive cavity, and now and then to withdraw the pseudopods and send out from one to three long, delicate flagella (*fl*). Thus the endoderm-cells of Hydra illustrate in a very instructive manner the essential similarity of flagella and pseudopods. In the hypostome the endoderm is thrown into longitudinal folds, so as to allow of the dilatation of the mouth in swallowing.

Amongst the ordinary endoderm-cells are found long narrow cells of an extremely granular character. They are specially abundant in the distal part of the body, beneath the origins of the tentacles and in the hypostome, but are absent in the tentacles and in the foot. There is no doubt that they are *gland-cells*, their secretion being a fluid used to aid in the digestion of the food.

In *Hydra viridis* the endoderm-cells (Fig. 82, D) contain chromatophore-like bodies (*chr*) coloured green by chlorophyll (p. 250), the function of which we have already considered (p. 252). It has been proved, however, that these are not actual parts of the endoderm-cells, but are distinct Sphærella-like organisms known as *Zoochlorellæ*, which are passed on from one generation of the Hydra to another by entering its developing eggs. Such an intimate living-together of two organisms is known as *symbiosis*. It differs essentially from parasitism (see p. 278), in which one organism preys upon another, the host deriving no benefit but only harm from the

presence of the parasite. In *symbiosis*, on the contrary, the two organisms are in a condition of mutually beneficial partnership. The carbon dioxide and nitrogenous waste given off by the cells of the Hydra serve as a constant food-supply to the Zoochlorella: at the same time the latter by decomposing the carbon dioxide provides the Hydra with a constant supply of oxygen, and also with two important foodstuffs—starch and proteins, which, after solution, diffuse from the protoplasm of the Zoochlorella into that of the endoderm-cells. The latter may therefore be said to keep the Zoochlorellæ constantly manured, while the Zoochlorellæ in return supply them with oxygen and ready-digested food. In the endoderm of *H. fusca* bodies of an orange or brown colour are present which are devoid of chlorophyll.

Muscle-processes also exist in connection with the endoderm-cells, and they are said to take a transverse or circular direction, *i.e.*, at right angles to the similar processes of the ectoderm cells.

Nutrition.—When a water-flea or other minute organism is swallowed by a Hydra, it undergoes a gradual process of disintegration. The process is begun by a solution of the soft parts due to the action of a digestive fluid secreted by the gland-cells of the endoderm; it is apparently completed by the endoderm-cells seizing minute particles with their pseudopods and engulfing them quite after the manner of Amœbæ. It is often found that the protrusion of pseudopods during digestion results in the almost complete obliteration of the enteric cavity.

It would seem, therefore, that in Hydra the process of digestion or solution of the food is to some extent *intracellular*, *i.e.*, takes place in the interior of the cells themselves, as *e.g.*, in Amœba or Paramœcium: it is,

however, largely *extra cellular* or *enteric, i.e.*, is performed in a special digestive cavity lined by cells (pp. 70 and 139).

The ectoderm-cells do not take in food directly, but are nourished entirely by diffusion from the endoderm. Thus the two layers have different functions: the ectoderm is protective and sensory—it forms the external covering of the animal, and receives impressions from without; the endoderm, removed from direct communication with the outer world, performs a nutrient function, its cells alone having the power of digesting food.

The essential difference between digestion and assimilation (p. 157) is here plainly seen: all the cells of Hydra assimilate, all are constantly undergoing waste, and all must therefore form new protoplasm to make good the loss. But it is the endoderm-cells alone which can make use of raw or undigested food: the ectoderm has to depend upon various products of digestion received by diffusion or osmosis from the endoderm.

It will be evident from the preceding description that Hydra is comparable to a colony of Amœbæ in which particular functions are made over to particular individuals—just as in a civilised community the functions of baking and butchering are assigned to certain members of the community, and not performed by all. Hydra is therefore an example of *individuation:* morphologically it is equivalent to an indefinite number of unicellular organisms: but these, acting in concert, some taking one duty and some another, form, physiologically speaking, not a colony of largely independent units (compare p. 272), but a single multicellular individual.

Reproduction.—Hydra has two distinct methods of reproduction, asexual and sexual.

Asexual multiplication takes place by a process of budding. A little knob appears on the body (Fig. 80, A, *bd*¹), and is found by sections to arise from a group of ectoderm-cells; soon, however, it takes on the character of a hollow outpushing of the wall containing a prolongation of the enteron and made up of ectoderm, mesoglœa, and endoderm (Fig. 82, A, *bd*¹). In the course of a few hours this prominence enlarges greatly, and near its distal end four or five hollow buds appear arranged in a whorl (Figs. 80, A, and 82, A, *bd*²). These enlarge and take on the characters of tentacles, and a mouth is formed at the distal end of the bud, which thus acquires the character of a small Hydra (Fig. 80, A, *bd*³). Finally the bud becomes constricted at its base, separates from the parent, and begins an independent existence. Sometimes, however, several buds are produced at one time, and each of these buds again before becoming detached: in this way temporary colonies are formed. But the buds always separate sooner or later, although they frequently begin to feed while still attached. In the Indian specimens more than two buds are rarely produced at a time, and an attached bud has not been seen to form buds on it.

It is a curious circumstance that Hydra can also be multiplied by artificial division: the experiment has often been tried of cutting the living animal into pieces, each of which is found to undergo *regeneration* into a perfect individual.

The sexual organs or *gonads* (p. 205) are of two kinds, *spermaries* and *ovaries*. In most species of Hydra both spermaries and ovaries are found in the same individual and Hydra is regarded as a *hermaphrodite* animal; but in India both kinds of sexual organs have never yet been found on the same individual.

The spermaries or testes (Figs. 80, B, and 82, A, *spy*)

are white conical elevations situated on the distal part of the body: as a rule not more than one or two are present at the same time, but there may be as many as twenty. They are perfectly colourless, even in the green and brown species, being obviously formed of ectoderm alone.

In the immature condition the spermary consists of a little heap of interstitial cells covered by an investment of somewhat flattened cells formed by a modification of the ordinary large cells of the ectoderm. When mature each of the small internal cells becomes converted into a *sperm* (p. 206), consisting of a small ovoid head formed from the nucleus of the cell, and of a long vibratile tail formed from its protoplasm (Fig. 82, G). By the rupture of the investing cells or wall of the spermary the sperms are liberated and swim freely in the water.

The ovaries (Figs 80, B, and 82, A, *ovy*) are found nearer the proximal end of the body, and vary in number from one to eight. When ripe an ovary is larger than a spermary, and of a hemispherical form. It begins, like the spermary, as an aggregation of interstitial cells, so that in their earlier stages the sex of the gonads is indeterminate. But while in the spermary each cell is converted into a sperm, in the ovary one cell (Fig. 82, A, *ov*) soon begins to grow faster than the rest, and becomes amœboid in form, sending out pseudopods amongst its companions and ingesting the fragments into which they become broken up, thus continually increasing in size at their expense. Ultimately the ovary comes to consist of this single amœboid *ovum* and of a layer of superficial cells forming a capsule for it. As the ovum grows, *yolk granules* (p. 207) are formed in it, and in *Hydra viridis* it also acquires Zoochlorellæ (p. 301).

When the ovary is ripe the ovum draws in its pseudopods and takes on a spherical form: the investing layer then bursts so as to lay bare the ovum and allow of the free access to it of the sperms. One of the latter conjugates with the ovum, producing an *oosperm* (p. 209) or unicellular embryo.

The oosperm undergoes *segmentation*, dividing into a number of cells which constitute a *morula* or *polyplast* (p. 212), the outermost cells of which become changed into a hard shell or capsule, which eventually bursts and sets free the embryo. The embryo develops into a Hydra, its cells becoming differentiated into ectoderm and endoderm, the enteron and mouth being formed, and the tentacles budding out around the latter.

It was stated on p. 304 that in a budding Hydra the buds sometimes do not become detached at once, but may themselves bud while still in connection with the parent, temporary colonies being thus produced.

Suppose the state of things to continue indefinitely; the result would be a tree-like colony or compound organism consisting of a stem with numerous branchlets each ending in a Hydra-like zooid. Such a colony would bear much the same relation to Hydra as Carchesium or Epistylis bears to Vorticella.

As a matter of fact this is precisely what happens in a great number of animals allied to Hydra and known by the name of *Zoophytes* or *Hydroid polypes*.

Obelia.—A very convenient genus of Hydroids for our purpose is *Obelia*, which occurs in the form of a delicate, whitish or light-brown, almost fur-like growth on seaweed, the wooden piles of piers, etc. It consists of branched filaments about the thickness of fine sewing-cotton: of these, some are closely adherent to the timber, and serve for attachment, while others are given off at

right angles, and present at intervals short lateral branches, each terminating in a bud-like enlargement.

The structure is better seen under a low power of the microscope. The organism (Fig. 84) is a colony, consisting of a common stem or axis, on which are borne numerous zooids (compare p. 272). The axis consists of a horizontal portion, resembling a root or creeping stem, and of vertical axes, which give off short lateral branches in an alternate manner, bearing the zooids at their ends. At the proximal ends of the vertical axes the branching often becomes more complex: the offshoots of the main stem, instead of ending at once in a zooid, send off branches of the third order on which the zooids are borne. In many cases, also, branches are found to end in simple club-like dilatations (*Bd.* 1, 2): these are immature zooids.

Structure of a Polype.—The large majority of the zooids are little Hydra-like bodies, the *polypes* or *hydranths*, each with a hypostome or *manubrium* (*mnb*) and a circlet of about two dozen tentacles. Less numerous, and found chiefly towards the proximal region of the colony, are long cylindrical bodies or *blastostyles* (*bls*), each bearing numerous small lateral offshoots, varying greatly in form according to their stage of development, and known as *medusa-buds* (*m. bd*); these will be considered presently.

Examination under a high power, either of an entire branch or of sections, shows that the polypes have essentially the structure of a Hydra, consisting of a double layer of cells—ectoderm (with nematocysts) and endoderm—separated by a supporting lamella or mesoglœa and enclosing a digestive cavity (*ent*) which opens externally by a mouth placed at the summit of the hypostome. The mouth is capable of great dilatation

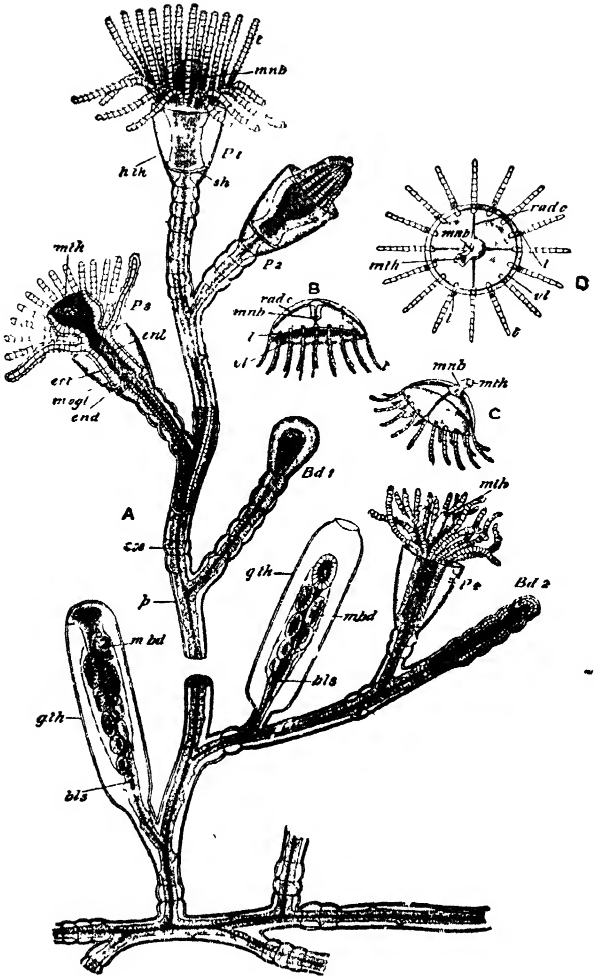

FIG 84 —**Obelia.** A, portion of a colony with certain parts shown in longitudinal section (× 10), B, medusa (× 5), C, the same with reversed umbrella, D, the same, oral aspect *Bd 1, 2,* buds, *bls* blastostyle; *cœ* cœnosarc, *ect* ectoderm, *end* endoderm, *ent* enteric cavity; *g th* gonotheca; *h th* hydrotheca; *l* lithocyst; *m bd* medusa-bud, *mnb.* hypostome or manubrium, *msgl.* mesoglœa, *mth.* mouth, *p* perisarc, *P. 1, 2, 3,* polypes, *rad c* radial canal; *t.* tentacle; *vl* velum. (From Parker and Haswell's *Zoology,* reduced.)

and contraction, and accordingly the hypostome appears now conical, now trumpet-shaped.

The tentacles, however, differ from those of Hydra in two important respects. In the first place they are solid: the endoderm, instead of forming a lining to a prolongation of the enteron, consists of a single axial row of large cells with thick cell-walls and vacuolated protoplasm. Then in the position of the muscle-processes of Hydra there is a layer of spindle-shaped fibres many times longer than broad, and provided each with a nucleus. Such *muscle-fibres* are obviously cells greatly extended in length (p. 117), so that the ectoderm-cell of Hydra with its continuous muscle-*process* is here represented by an ectoderm-cell with an adjacent muscle-*cell*. We thus get a partial intermediate layer of cells between the ectoderm and endoderm, in addition to the gelatinous mesoglœa; and so, while a hydroid polype is, like Hydra, *diploblastic* (p. 296), it shows a tendency towards the assumption of a three-layered or *triploblastic* condition (compare p. 213).

The part of the stem and branches continuous with the bases of the polypes, which is known as the *cœnosarc*, is formed of the same layers and contains a cavity continuous with those of the hydranths; thus the structure of a hydroid polype is, so far, simply that of a Hydra in which the process of budding has gone on to an indefinite extent and without separation of the buds

There is, however, an additional layer added for protective and strengthening purposes. It is evident that such a colony would, if formed only of soft ectodermal and endodermal cells, be so weak as to be hardly able to bear its own weight even in water. To remedy this a layer of transparent, yellowish substance of horn-like consistency, called the *perisarc*, is developed outside the ectoderm of the cœnosarc, extending on to

the branches and continuous with a glassy, cup-like investment, or *hydrotheca,* around the base of each polype, and with a transparent case, or *gonotheca,* enclosing each blastostyle. Each hydrotheca (*h.′th*) has the form of a vase or wine-glass, and is perfectly transparent and colourless. A short distance from its narrow or proximal end, it is produced inwards into a sort of circular shelf (*sh*), perforated in the centre: upon this the base of the polype rests, and through the aperture it is continuous with the common stem. When irritated—by a touch or by the addition of alcohol or other poison—the polype undergoes a very marked contraction: it suddenly withdraws itself more or less completely into the theca, and the tentacles become greatly shortened and curved over the manubrium (*P.* 2). At the base of each zooid or branch the perisarc presents several annular constrictions, giving it a ringed appearance: for the most part it is separated by an interval from the cœnosarc, but processes of the latter extend outwards to it at irregular intervals, and at first (*Bd.* 2) the two layers are in close apposition.

It is this layer which, when the organism dies and decays, is left as a semi-transparent, branched structure resembling the living colony in form except that polypes, blastostyles, and medusa-buds are wanting. The perisarc is therefore a supporting organ or skeleton, not, like our own bones, formed in the interior of the body (*endoskeleton*), but, like the shell of a prawn or lobster, lying altogether outside the soft parts (*exoskeleton*).

As to the mode of formation of the perisarc:—we saw that many organisms, such as Sphærella and Amœba, are able to form a cyst or cell-wall, by secreting or separating from the surface of the protoplasm a succession of layers either of cellulose or of a transparent horn-like substance (pp. 244 and 250). But

Amœba and Sphærella are unicellular, and are therefore free to form this protective layer at all parts of their surface. The ectoderm-cells of Obelia, on the other hand, are in close contact with their neighbours on all sides and with the mesoglœa at their inner ends, so that it is not surprising to find the secretion of skeletal substance taking place only at their outer ends. As the process takes place simultaneously in adjacent cells, the result is a continuous layer common to the whole ectoderm instead of a capsule to each individual cell. It is to an exoskeletal structure formed in this way, *i.e.*, by the secretion of successive layers from the free faces of adjacent cells, that the name *cuticle* is in strictness applied in multicellular organisms.

Structure of a Medusa.—In the blastostyles both mouth and tentacles are absent, the zooid ending distally in a flattened disc: the hydrotheca of a polype is represented by the gonotheca (*g. th*), which is a cylindrical capsule enclosing the whole structure, but ultimately becoming ruptured at its distal end to allow of the escape of the medusa-buds. These latter are, in the young condition, mere hollow offshoots of the blastostyle: when fully developed they have the appearance of saucers attached by the middle of the convex surface to the blastostyle, produced at the edge into sixteen very short tentacles, and having a blunt process, the *manubrium*, projecting from the centre of the concave surface. They are ultimately set free through the aperture in the gonotheca as little *medusæ* or jelly-fish (B–D).

The structure of a medusa must now be described in some detail. The saucer-shaped "bell" or *umbrella* (Figs. 84, B–D, 85, and 86) is formed of a gelatinous substance (Fig. 86, D, *msgl*) covered both on its inner surface, or *sub-umbrella*, and on its outer surface, or *ex-umbrella*, by a thin layer of delicate cells (*ect*). The

clapper-like *manubrium* (*mnb*) is formed of two layers of cells, precisely resembling the ectoderm and endoderm of Hydra, and separated by a thin mesoglœa, it is hollow, its cavity (*ent. cav*) opening below, *i.e.*, at its distal or free end, by a four-sided aperture, the *mouth* (*mth*), used by the medusa for the ingestion of food. Very commonly as the medusa swims the umbrella becomes turned inside out, the sub-umbrella then

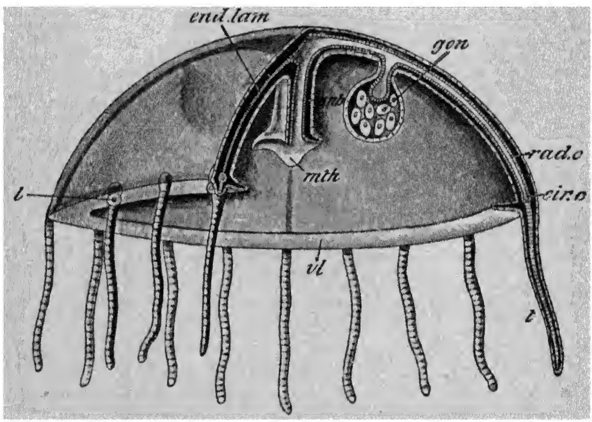

FIG 85 —Dissection of a **Medusa** (× 25) with rather more than one-quarter of the umbrella and manubrium cut away (diagrammatic) The ectoderm is dotted, the endoderm striated, and the mesoglœa black. ***cir c*** circular canal, ***end lam*** endoderm-lamella, ***gon*** gonad, ***l.*** lithocyst, ***mnb*** manubrium, ***mth*** mouth, ***rad c*** radial canal, ***vl*** velum

forming the convex surface and the manubrium springing from its apex (Fig. 84, C). At its upper (attached or proximal) end the cavity of the manubrium is continued into four narrow, *radial canals* (Figs. 84, B, D, and 85, *rad. c*, and Fig. 86, D, and D′, *rad*) which extend through the gelatinous substance of the umbrella at equal distances from one another, like four meridians, and finally open into a *circular canal* (*cir. c*) which runs round the edge of the umbrella. By means of this

system of canals the food, taken in at the mouth and digested in the manubrium, is distributed to the entire medusa. The canals are lined by a layer of cells (Fig. 86, D, and D′, *end*) continuous with the inner layer or endoderm of the manubrium; and extending from one canal to another, in the gelatinous substance of the umbrella, is a delicate sheet of cells, the *endoderm-lamella* (D′, *end. lam*).

The edge of the umbrella is produced into a very narrow fold or shelf, the *velum* (Fig. 85, *vl*, Fig. 86, *v*), and gives off the tentacles (*t*), which are sixteen in number in the newly-born medusa, very numerous in the adult. At the bases of eight of the tentacles—two in each quadrant—are minute globular sacs (*l*), each containing a calcareous particle or *lithite*. These are the *marginal sense-organs* or *lithocysts*: they were formerly considered to be organs of hearing, and are hence frequently called "otocysts": in all probability their function is to guide the medusa by enabling it to judge of the direction in which it is swimming. The marginal organs in this case may therefore be looked upon as organs of the sense of direction or of equilibration, and may be spoken of as *statocysts* (compare p. 201). The velum consists of a middle layer of mesoglœa with ectoderm on either side: there is no extension of endoderm into it. The tentacles, like those of the polype, are formed of a core of endoderm covered by ectoderm, which encloses numerous stinging-capsules.

Hydroid and Medusa compared.—At first sight there appears to be very little resemblance between a medusa and a polype, but it is really quite easy to derive the one form from the other.

Suppose a simple polype or Hydra-like body with four tentacles (Fig. 86, A, A′) to have the region from which the tentacles spring pulled out so as to form a hollow,

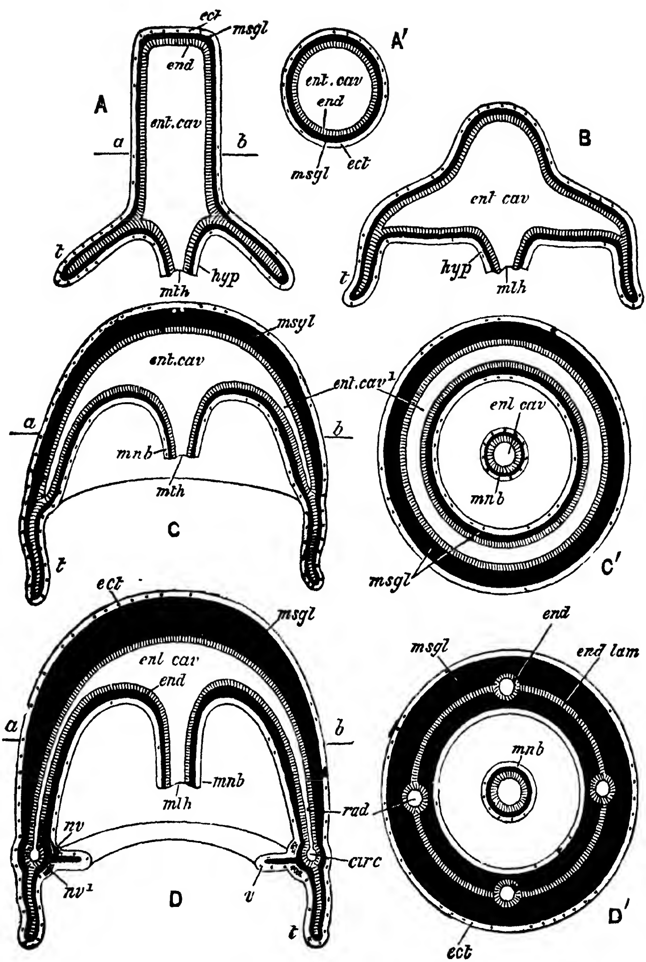

FIG. 86 — Diagrams illustrating the derivation of the medusa from the hydranth In the whole series of figures the ectoderm (*ect*) is dotted, the endoderm (*end*) striated, and the mesoglœa (*msgl*) black

A, longitudinal section of a simple polype showing the tubular body, with enteric cavity (*ent. cav*), hypostome (*hyp*), mouth (*mth*), and tentacles (*t*).

A′, transverse section of the same through the plane *a b*

B, the tentacular region is extended into a hollow disc

C, the tentacular region has been further extended and bent into a bell-like form,

the enteric cavity being continued into the umbrella (*ent. cav'*); the hypostome now forms a manubrium (*mnb*).
C', transverse section of the same through the plane *a b*, showing the continuous cavity (*ent. cav*) in the umbrella
D, fully formed medusa; the cavity in the umbrella is reduced to the radial (*rad*) and circular (*cir. c*) canals, the velum (*v*) is formed, and a double nerve-ring (*nv. nv'*) is produced from the ectoderm
D', transverse section of the same through the plane *a b*, showing the four radial canals (*rad*) united by the endoderm-lamella (*end. lam*), produced by partial obliteration of the continuous cavity (*ent. cav'*) in C. (From Parker's *Biology*)

transversely extended disc (B). Next, suppose this disc to become bent into the form of a cup with its concavity towards the hypostome, and to undergo a great thickening of its mesoglœa. A form would be produced like C, *i.e.*, a medusa-like body with umbrella and manubrium, but with a continuous cavity (C', *ent. cav'*) in the thickness of the umbrella instead of four radial canals. Finally, suppose the inner and outer walls of this cavity to grow towards one another and meet, thus obliterating the cavity, except along four narrow radial areas (D, *rad*) and a circular area near the edge of the umbrella (*cir. c*). This would result in the substitution for the continuous cavity of four radial canals opening on the one hand into a circular canal and on the other into the cavity of the manubrium (*ent. cav*), and connected with one another by a membrane—the *endoderm-lamella* (D', *end. lam*)—indicating the former extension of the cavity.

It follows from this that the inner and outer layers of the manubrium are respectively endoderm and ectoderm: that the gelatinous tissue of the umbrella is an immensely thickened mesoglœa: that the layer of cells covering both inner and outer surfaces of the umbrella is ectodermal: and that the layer of cells lining the system of canals, together with the endoderm-lamella, is endodermal.

Thus the medusa, the polype, and the blastostyle are similarly constructed or *homologous* structures (p. 229), and the hydroid colony is *trimorphic*, bearing zooids of three kinds. In some allied forms this individuation

may go still further, the zooids being of very various forms and performing diverse functions: such a colony is said to be *polymorphic*.

Morphological Differentiation.—Sooner or later the medusæ separate from the hydroid colony and begin a free existence. Under these circumstances the rhythmical contraction—*i.e.*, contraction taking place at regular intervals—of the muscles of the umbrella causes an alternate contraction and expansion of the whole organ, so that water is alternately pumped out of and drawn into it. The obvious result of this is that the medusa is propelled through the water by a series of jerks. The movement is due to the contraction of the muscle-processes and muscle-fibres of the sub-umbrella and velum, some of which differ from the similar structures in the polype in exhibiting a delicate transverse striation.

There is still another important matter in the structure of the medusa which has not been referred to. At the junction of the velum with the edge of the umbrella there lies, immediately beneath the ectoderm, a layer of peculiar, branched cells, containing large nuclei and produced into long fibre-like processes. These *nerve-cells* (pp. 177 and 300) are so disposed as to form a double ring round the margin of the bell, one ring (Fig. 86, D, *nv*) being immediately above, the other (*nv'*) immediately below the insertion of the velum. An irregular network of similar cells and fibres occurs on the inner or concave face of the bell, between the ectoderm and the layer of muscle-fibres. The whole constitutes the *nervous system* of the medusa; the double nerve-ring is the *central*, the network the *peripheral* nervous system (p. 163).

Some of the processes of the nerve-cells are connected with ordinary ectoderm-cells, which thus as it were con-

nect the nervous system with the external world: others, in some instances at least, are probably directly connected with muscle-fibres.

We thus see that while the manubrium of a medusa has the same simple structure as a polype, the umbrella has undergone a very remarkable differentiation of its tissues. Its ordinary ectoderm-cells, instead of being large and eminently contractile, form little more than a thin cellular skin or *epithelium* (p. 115) over the gelatinous mesoglœa: they have largely given up the function of contractility to the muscle-processes or fibres, and serve merely as a protective and sensitive layer.

Similarly the function of automatism, possessed by the whole body of Hydra, is made over to the group of specially modified ectodermal cells which constitute the central nervous system. If a Hydra is cut into any number of pieces each of them is able to perform the ordinary movements of expansion and contraction, but if the nerve-ring of a medusa is removed by cutting away the edge of the umbrella, the rhythmical swimming movements stop dead: the umbrella is in fact permanently paralysed.

It is not, however, rendered incapable of movement, for a sharp pinch, *i.e.*, an external stimulus, causes a single contraction, showing that the muscles still retain their irritability. But no movement takes place without such external stimulus, each stimulus giving rise infallibly to one single contraction: the power possessed by the entire animal of independently originating movement, *i.e.*, of supplying its own stimuli, is lost with the central nervous system (compare p. 183).

Another instance of morphological and physiological differentiation is furnished by the marginal sense-organs situated at the base of the tentacles (p. 313).

Reproduction.—The polype and medusa are respec-

tively nutritive and reproductive in function, the reproductive zooids becoming detached and swimming off to found a new colony elsewhere: the polypes are purely nutritive zooids; the medusæ, although capable of feeding, are specially distinguished as reproductive zooids. Hanging at equal distances from the sub-umbrella, in immediate relation with the radial canal, are four ovoid gonads (Fig. 85, *gon*), each consisting of an outer layer of ectoderm continuous with that of the sub-umbrella, an inner layer of endoderm continuous with that of the radial canal and enclosing a prolongation of the latter, and of an intermediate mass of cells which have become differentiated into ova or sperms. As each medusa bears organs of one sex only (spermaries or ovaries, as the case may be), the individual medusæ are *diœcious*, and not, like Hydra, monœcious. It will be noticed that the gonad has the same general structure as an immature zooid—an out-pushing of the body-wall consisting of ectoderm and endoderm, and containing a prolongation of the enteric cavity.

The medusæ, when mature, become detached and swim away from the hydroid colony. The sperms of the males are shed into the water and carried to the ovaries of the females, where they fertilise the ova, converting them, as usual, into oosperms.

Alternation of Generations.—The oosperm undergoes segmentation, forming a polyplast or morula (p. 212): ectoderm and endoderm become differentiated, and the ectoderm-cells acquire cilia, by means of which the embryo now swims freely in the water. An enteron appears in the endoderm, and in this stage the embryo, which has an elongated form, is known as a *planula*. It then loses its cilia and settles down on a rock, shell, sea-weed, or other submarine object, assuming a vertical position, with its broader end fixed to the support.

The attached or proximal end widens into a disc of attachment, a dilatation is formed a short distance from the free or distal end, and a thin cuticle is secreted from the whole surface of the ectoderm. From the dilated portion short buds arise in a circle: these are the rudiments of the tentacles: the narrow portion beyond their origin becomes the hypostome. Soon the cuticle covering the distal end is ruptured so as to set free the growing tentacles: an aperture, the mouth, is formed at the end of the hypostome, and the young hydroid has very much the appearance of a Hydra with a broad disc of attachment, and with a cuticle covering the greater part of the body. Extensive budding next takes place, the result being the formation of the ordinary hydroid colony.

Thus from the oosperm or impregnated egg-cell of the medusa the hydroid colony arises, while the medusa is produced by budding from the hydroid colony. We have what is called an *alternation of generations*, the *asexual generation* or *agamobium* (hydroid colony) giving rise by budding to the *sexual generation* or *gamobium* (medusa), which in its turn produces the agamobium by a sexual process, *i.e.*, by the conjugation of ovum and sperm (compare p. 209). This form of alternation of generations is known as *metagenesis*.

Phylum Cœlenterata. — Hydra and Obelia both belong to the simplest class—the *Hydrozoa*—of the phylum **Cœlenterata**: this phylum includes all the polypes or zoophytes, the jelly-fishes, and the anemones and corals. In all there is an ectoderm and an endoderm, separated by a mesoglœa, which may consist, as in Hydra, of a structureless membrane containing no cells, or may be gelatinous as in the medusa, and may even contain cells, thus assuming more the character of an intermediate cell-layer or mesoderm. There is no body-cavity or

cælome (p. 20) surrounding the digestive cavity or enteron, and tentacles are present round the mouth. Organs of offence occur in the form of thread-cells or nematocysts. The phylum consists of the following classes among others :—

Class **Hydrozoa.**—Cœlentrates in which the dominant phase is a Hydra-like form, either solitary or forming a branched colony. In the colonial forms, special individuals are usually modified for reproduction, and in some cases these become transformed into free-swimming medusæ. The sexual cells are always discharged directly into the surrounding water. *Hydra, Obelia.*

Class **Scyphozoa.**—Cœlentrates in which the dominant phase is the " medusa " or " jelly-fish," which can be distinguished easily from the hydrozoan medusa by the presence of notches, usually eight in number, in the margin of the umbrella. The medusæ may develop directly from fertilised eggs, but in most cases they are formed by the repeated transverse division of a small hydra-like but wide-mouthed " scyphistoma." The sexual cells are discharged first within the body-cavity. *Aurelia.*

Class **Anthozoa.**—There are no medusæ among the Anthozoa. The polypes may be distinguished from those of the Hydrozoa by the presence of a well-developed stomodæum or gullet, which is fastened to the body-wall by a number of radially arranged membranes called mesenteries. Many of the forms are solitary, but the majority produce colonies by budding. Most of the Anthozoa secrete a calcareous skeleton, known as coral. Sea-anemones. Stony corals. Red corals.

In all the higher phyla a definite mesoderm is developed in the embryo in addition to the ectoderm and endoderm (*triploblastic* condition), and in nearly all cases

there is a definite cavity or cœlome present in the mesoderm: hence all these animals are often included together as the **Cœlomata.**

PRACTICAL DIRECTIONS

Hydra.

A.—Examine some living Hydræ in a vessel of water, with the naked eye or with a pocket lens, and note the differences in form according to the degree of contraction. The animal is usually attached to foreign bodies (weeds, &c.) at one end and at the other end a number of tentacles (usually four to six) are given off In the expanded state the body and tentacles are greatly elongated and thread-like, while when contracted the body is more globular, and the tentacles appear like small knobs. Observe the method of seizing food Place a specimen on a slide in a drop of water, together with a small piece of water-weed or two broken pieces of thick cover-glass to prevent crushing, and then put on a cover-glass. Wait till the animal is fully expanded, and then examine with the low power. Note (Figs. 80 and 81) —

1 The *body*, enclosing the *digestive cavity* or *enteron*, which opens by the *mouth* at the distal end of the animal, at the summit of a conical *hypostome*. At the proximal end is the *foot*, or *disc* of attachment.

2. The *tentacles*, arranged in a single circlet or *whorl* around the base of the hypostome. They are hollow, and their cavities communicate proximally with the general digestive cavity of the body. On their surface are a number of small knobs

3. The contractions of the body and tentacles.

4. The *structure of the body-wall*, which is made up of (*a*) an outer layer of colourless cells (*ectoderm*), and (*b*) an inner layer of cells (*endoderm*) lining the digestive cavity. Between these two layers is a thin gelatinous non-cellular *supporting lamella* or *mesoglœa*, not easily seen with the low power. (The tentacles have a similar structure, the details of which cannot be made out with the low power.) Sketch.

Put on the high power and examine a tentacle, focussing on to the surface as well as deeper, so as to get an *optical section* (Fig 82, A). Note :—

5. The relations of the ectoderm, endoderm, and support-

ing lamella, and the nuclei of the ectoderm and endoderm cells.

6. The structure of the *ectoderm* :—(*a*) *large conical cells* with their broader ends outwards, arranged in a single row, and differing in form according to the state of contraction. The spaces between the inner narrower ends of these are filled up with (*b*) smaller rounded *interstitial cells* (absent on the foot) ; (*c*) *thread-cells* or *nematocysts* (Fig. 83)—oval capsules containing a spirally-wound thread, developed within certain of the interstitial cells called *cnidoblasts*, and when fully formed, found imbedded in or between the large ectoderm-cells ; they are much more numerous on the tentacles than on the body, causing the knobs referred to above. Each cnidoblast gives rise to a small process—the trigger-hair or *cnidocil*, which projects from the surface Notice the discharged thread-cells, and observe that each consists of a flask-like base (to which part of the protoplasm and the nucleus of the burst cnidoblast usually remains attached) and a long filament, with three large and several smaller spines or barbs at its proximal end. (Smaller thread-cells, with thicker threads and no spines, are also present ; some of these have long, spirally-coiled threads, others shorter, straight threads. These can be seen later on.)

7. The *endoderm*, consisting of a single layer of large amœboid cells. Note the currents in the tentacles, which are produced by long vibratile *flagella* present on many of the endoderm-cells.

8. The thin transparent *supporting lamella*. Sketch.

9. Treat a specimen with methyl-green. A slight pressure on the cover-glass will crush the animal, and render the interstitial cells and thread-cells especially distinct. Note also other isolated cells of the ectoderm and endoderm. Sketch.

10. Examine a specimen with buds in different stages of development, and note as much as possible of the mode of *asexual reproduction* by *gemmation*. Sketch.

B.—11. If none of your specimens bears *sexual organs*, try to procure a mounted preparation which shows them, and examine first with the low, and then the high power. Note—(*a*) the *spermaries*—conical swellings on the distal part of the body; they are covered with large ectoderm-cells, and contain numerous interstitial cells, each of which eventually gives rise to a *sperm* with a " head " and vibratile " tail." These are discharged at the apex of the cone, which when ripe may be ruptured by a slight pressure on

the cover-glass. (*b*) The *ovaries* (sometimes only one), generally situated nearer the proximal end of the body. They are larger than the spermaries and more spherical, but at first have a similar structure. When ripe a single *ovum* is found in each Sketch.

C.—Place some Hydræ in a watch-glass with a very small amount of water, and when they have expanded, pour quickly over them a warm saturated solution of corrosive sublimate in alcohol or water. Wash several times with weak alcohol, stain for a few minutes with borax-carmine or hæmatoxylin, and wash with weak and then with stronger alcohol. Place in absolute alcohol for a few minutes, and afterwards in turpentine, xylol, or oil of cloves; mount in balsam. Work through §§ 5—8 again, noting especially the characters of the various cells and their nuclei, as well as—

12. The *contractile processes* coming off from the inner ends of the large ectoderm-cells (Fig 82, C). These extend longitudinally, and lie against the outer surface of the supporting lamella. Sketch.

D —Examine transverse sections through the body or tentacles (Fig. 82, B) prepared as directed on p. 145, after killing and fixing the specimens as above. Work through §§ 6—8 again, noting the various cells and their nuclei, &c. Observe especially—

13. (*a*) *The contractile processes of the ectoderm-cells*, which will be cut across transversely, so as to appear as dots just outside the supporting lamella; (*b*) the *amœboid* and *vacuolated* character of the *endoderm*-cells. (Special methods of preparation are necessary in order to show the flagella) Sketch.

Obelia.[1]

If possible, examine first alive, and then kill and stain as directed in the case of Hydra.

1. Examine under the low power and note :—

(*a*) The *polypes*, with their *tentacles* and *hypostome*, expanded and contracted; and the immature polypes. (*b*) The *blastostyles* and *medusa-buds*. (*c*) The *cœnosarc* and the *perisarc*, *hydrothecæ*, and *gonothecæ* (Fig. 84). Sketch.

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[1] Preserved specimens both of the colonial and medusa stage of Obelia or some other Hydroid (as well as other marine animals described in this book) can be obtained from the Government Fisheries Station, Ennur. (Madras Presidency)

2. Then stain, put on the high power and make out the minute structure of the polypes, noting the—

(*a*) *Mouth*, (*b*) *enteron*, (*c*) *ectoderm*, *supporting lamella*, and *endoderm* (solid in the tentacles). On the blastostyles examine the *medusa-buds*. (If you wish to make permanent preparations, mounted in balsam, use the method given for Hydra.)

Sketch an optical section of a polype and blastostyle.

Sections of an entire branch, prepared in the usual way (see p. 145), should also be made Select for examination those which pass as nearly as possible through the vertical and transverse axes of a polype, and compare with your sections of Hydra.

3. Place a medusa (Figs 84, B—D, and 85) on a slide with the sub-umbrella surface uppermost, stain, and mount carefully in glycerine. Note—

(*a*) The *umbrella*, (*b*) *manubrium* and *mouth*, (*c*) *tentacles*, (*d*) *radial* and *circular canals*, (*e*) *velum*, (*f*) *gonads*, and (*g*) *lithocysts* (often difficult to recognise in preserved specimens). Sketch.

CHAPTER V

THE EARTHWORM : NEREIS—CHARACTERS OF THE PHYLUM ANNELIDA—CLASSIFICATION

THE general form and appearance of an earthworm are familiar to everyone. In this country there are a number of different genera of earthworms belonging to several families, common among which are Pheretima and Helodrilus; these are widely different in their anatomy and belong to quite distinct families. In one and the same place a number of different genera of earthworms may be found, but *Pheretima posthuma* is more or less common all over India and is here taken as the type. Other species of this widely distributed genus differ from that species in minor points of structure only, and where specimens of *P. posthuma* may not be readily obtainable, any other species may be substituted, and the following description will sufficiently serve the purpose.

Action of Earthworms on the Soil.—Earthworms burrow into the soil and live on decaying leaves and other organic matter, which they swallow together with a considerable quantity of earth. This earth, mingled with the undigested portions of the food, is passed from the body on to the surface of the ground in the form of the well-known little heaps or " castings " which you must have noticed in gardens and fields,

especially after rain, when the worms come more frequently to the surface. In this way a quantity of finely divided earth, mixed with the fæces of the worms, is constantly being spread out on the surface of the soil, and Darwin calculated that on an average a layer of earth about one-fifth inch in thickness, or about ten tons an acre, is thus brought to the surface in the course of a year. Earthworms are therefore good friends to the gardener and agriculturist, as they are continually ploughing and manuring the soil, and in doing so they gradually cover up stones and other objects lying on the surface.

External Features.—The body of the earthworm is long and narrow, approximately cylindrical in shape, and bilaterally symmetrical (p. 293): a full-grown specimen of *P. posthuma* is usually found to be four to six inches in length, and about a quarter of an inch in diameter. Anteriorly it is bluntly pointed, and its greatest diameter is reached a little way behind the anterior end. In the ordinary creeping movements of the animal, which are effected by the alternate contraction and extension of its body, the anterior end is directed forwards. The colour is brown in most species, and is paler on the lower or ventral than on the upper or dorsal side. The worms belonging to the genus Pheretima are very active, and some have the curious habit of protruding their buccal cavity beyond the anterior end of the worm.

The surface of the body is distinctly marked by transverse annular grooves into *body-segments* or *metameres* (Fig. 87, A), the number of which is about 100–120, more or less. This external segmentation corresponds with an internal segmentation of the body; but some of the anterior segments show a secondary annulation appearing bi- or even tri-annulate. At the extreme anterior end is

section of the body has, therefore, the general character of two concentric circles.

Hydra and Earthworm compared.—It will be remembered that a transverse section of Hydra has the character of two concentric circles, formed respectively of ectoderm and endoderm (Fig. 82, B, p. 297), the two layers being, however, only separated by the thin mesoglœa. At first sight, then, it seems as if we might compare the earthworm to a Hydra in which the ectoderm and endoderm, instead of being in contact, were separated by a wide interval; we should then compare the body-wall of the earthworm with the ectoderm of Hydra, and its enteric canal with the endoderm. But this comparison would only express part of the truth.

A thin transverse section (Fig. 88) shows the body-wall of the earthworm to consist of several distinct layers. Outside is a thin transparent *cuticle* (*c*) showing no structure beyond a series of intersecting oblique lines. Next comes a layer of epithelium, the *epidermis* or *deric epithelium* (*ep*). Within this is a very thin connective-tissue layer representing the *dermis* (p. 136), and a double layer of *muscle-fibres* by means of which the movements of the body are produced—an outer, in which the fibres extend transversely round the body (*cm*), and a much thicker inner layer consisting of longitudinal fibres, in section seen as bundles of fibres which have been cut across (*lm*). Finally, within the muscular layer and lining the cœlome is a thin *peritoneal membrane* (parietal layer, compare p. 27), on the inner surface of which is a very thin layer of cells, the *cœlomic epithelium*.

A transverse section of the intestine shows an inner layer of columnar *enteric epithelium* (*i. ep*) (compare p. 115), a very thin middle layer composed of muscle-fibres and connective-tissue, and an outer layer of large

yellow cells, the function of which is said to be excretory, and which correspond to a special development of the cœlomic epithelium covering the visceral layer of the peritoneal membrane which invests the intestine.

We are now in a better position to compare the transverse section of the Hydra and the earthworm. The epidermis of the earthworm being the outermost cell-layer is to be compared with the ectoderm of Hydra, and its cuticle with the layer of the same name which, though absent in Hydra, is present in the stem of hydroid polypes, such as Obelia (viz., the perisarc). The enteric epithelium of the earthworm, bounding as it does the digestive cavity, is clearly comparable with the endoderm of Hydra. So that we have the double layer of muscle-fibres and the two layers of peritoneum not represented in Hydra, in which their position is occupied merely by the mesoglœa. The muscle-fibres are not of the striped kind, like those in the corresponding position in the frog (p. 118).

But it will be remembered that in Medusæ there is sometimes found a layer of separate muscle-fibres between the ectoderm and the mesoglœa, and it was pointed out (p. 309) that such fibres represented a rudimentary intermediate cell-layer or mesoderm. We may therefore consider the muscular layer and the peritoneum of the earthworm as mesoderm, and we may say that in this animal, as in the frog (p. 214, and Fig. 70), the mesoderm is divisible into an outer or *parietal layer*, and an inner or *visceral layer*.

The parietal layer is in contact with the ectoderm or deric epithelium, and with it forms the body-wall; the visceral layer is in contact with the endoderm or enteric epithelium, and with it forms the enteric canal. The cœlome separates the parietal and visceral layers from one another, and is lined throughout by cœlomic epithelium.

The relation between the diploblastic polype and the triploblastic worm may therefore be expressed in a tabular form as follows:

Hydroid.		*Earthworm*[1]
Cuticle		Cuticle.
Ectoderm.		Deric epithelium or epidermis.
Mesoderm . (rudimentary)	Parietal layer	Connective-tissue and muscle-fibres. Peritoneum with its cœlomic epithelium (parietal layer).
	Visceral layer	Peritoneum with its cœlomic epithelium (visceral layer). Connective-tissue and muscle-fibres.
Endoderm		Enteric epithelium.

Strictly speaking this comparison does not hold good of the anterior and posterior ends of the worm: at both mouth and anus the deric passes insensibly into the enteric epithelium, and the study of development shows that the cells lining both the anterior and posterior ends of the canal are ectodermal (compare pp. 215 and 218).

It is important that you should, before reading further, understand clearly the general composition of a triploblastic animal as typified by the earthworm, which may be summarised as follows. It consists of two tubes formed of epithelial cells, one within and parallel to the other, the two being continuous at either end of the body where the inner tube (enteric epithelium) is in free communication with the exterior; the outer tube (deric epithelium) is lined by a layer of connective-tissue and

[1] It will be seen that the relations of these layers in the earthworm and frog are similar, except that in the latter the cuticle is wanting (compare Figs. 6, 43, and 44).

muscle-fibres, within which is a thin peritoneum lined by cœlomic epithelium, the three together forming the body-wall; the inner tube (enteric epithelium) is covered externally by a layer of muscle-fibres and connective-tissue and a thin peritoneum covered by cœlomic epithelium, which form with it the enteric canal; lastly, the body-wall and enteric canal are separated by a considerable space, the cœlome.

Cœlome.—The enteric canal is not, as might be supposed from the foregoing description, connected with the body-wall only at the mouth and anus, but is supported in a peculiar way. There is no dorsal mesentery as in the frog (p. 27), but a series of transverse vertical partitions or *septa* (Fig. 89) extends right across the body-cavity, each being perforated by the canal. The septa are regularly arranged and correspond in position with the external grooves by which the body is divided into metameres. Thus the transverse or metameric segmentation affects the cœlome as well as the body-wall, the former being divided up into a series of chambers, which, however, communicate with one another ventrally where the septa are incomplete (Fig. 89). There are no septa in the first four segments; the first definite septum, thin and membranous, is between the fourth and fifth segments. The next three septa, *i.e.*, between the fifth and sixth, sixth and seventh, and seventh and eighth, are thickened and muscular. The septum between the eighth and ninth is also somewhat thickened. One of the septa, either between the eighth and ninth or between the ninth and tenth segments, is absent. Each septum is composed of a sheet of connective-tissue and muscle-fibres, and is covered on both sides by cœlomic epithelium. The cœlome communicates with the exterior by a series of *dorsal pores* situated in the middle dorsal

and other digestible parts so as to allow of their absorption. It is very probable that the process is purely extra-cellular or enteric, the food being dissolved and rendered diffusible entirely in the cavity of the canal (p. 303). By the movements of the canal—caused partly by the general movements of the body and partly by the contraction of the muscles of the canal and septa aided by the action of the cilia—the contents are gradually forced backwards, and the earth and other indigestible matters expelled at the anus.

The cœlome is filled with a colourless transparent *cœlomic fluid* in which are suspended amœboid corpuscles or leucocytes like those of the frog's blood and lymph (p. 111), minute non-granular cells, cells with refractile granules, and yellow cells in various stages of degeneration. The function of this cœlomic fluid is phagocytic and excretory. Any bacteria or other particles that may gain their entrance into the body of the earthworm are destroyed by the leucocytes, and degenerating yellow cells and other products of excretion are carried to the mouths of the nephridia or got rid of directly by the flow of some cœlomic fluid through the dorsal pores. To a limited extent the cœlomic fluid may also distribute the digested food in the enteric canal to all parts of the body.

Vascular System.—The earthworm, like the frog, possesses a series of *blood-vessels*, containing red blood, the whole of which form a single closed vascular system, there being no communication between them and any of the other cavities of the body. The main trunks have a longitudinal direction, the chief ones being a large *dorsal vessel* (Figs. 88 and 89, *d.b.v.*), running along the dorsal surface of the enteric canal, a *ventral* or *sub-intestinal* vessel, below the canal (*v.b.v.*), and a smaller *sub-neural* (*s.n.v.*) running ventral to the nerve-cord,

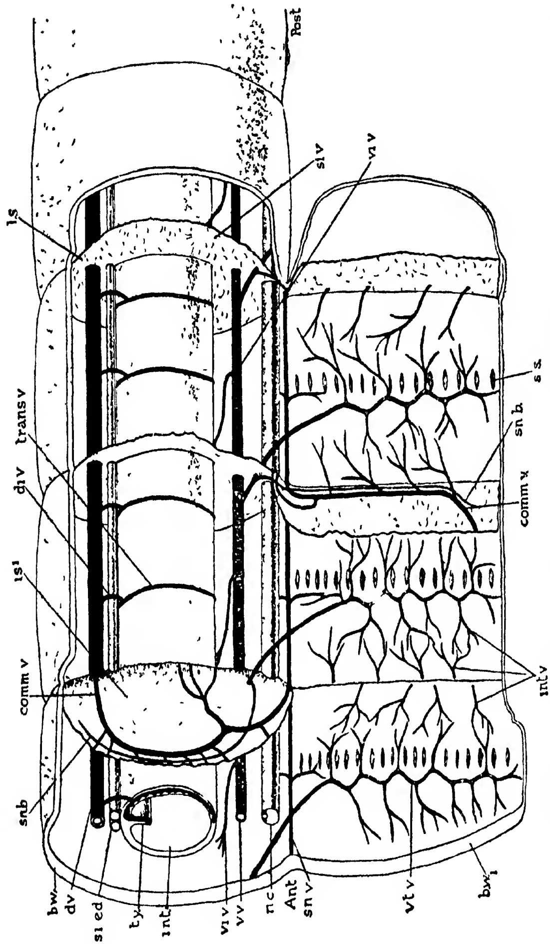


FIG 89A.—A diagrammatic representation of the circulatory system in the region of the body behind the fourteenth segment Five segments are shown with the greater part of the body-wall on the left side cut and reflected in order to show the blood-vessels, *b w*, body-wall, $b\,w_1$, reflected body-wall, *comm v*, commissural vessel, *d v*, dorsal vessel, *di v*, dorso-intestinal vessel, *int*, intestine, *i s*, intersegmental septum, $i\,s^1$, intersegmental septum turned forwards, *int v*, vessels supplying the body-wall, *n.c*, nerve-cord, *si e d*, supra-intestinal excretory ducts, *si v*, branches from the commissural to the gut-wall, *sn v*, subneural vessel *sn b*, vessel supplying septal nephridia, *s s*, setal-sac; *ty*, typhlosole, *trans v*, transverse vessel; *v v*, ventral vessel, *vi v*, vessel to the intestine, *vt v*, vessel to the body-wall. (After Karm Narayan Bahl)

the last named extending from the posterior end of the worm to the fourteenth segment anteriorly. All these longitudinal trunks give off branches to the various

parts of the body. The subneural is connected with the dorsal by a pair of lateral *commissural vessels* (Fig. 89A, *comm.v.*) in each segment, and there are two pairs of *transverse vessels* (*trans v.*) in each segment which encircle the gut and open into the dorsal vessel by small *dorso-intestinal vessels* (*di.v.*).

The blood flows forwards in the dorsal vessel and backwards in the ventral and sub-neural vessels. In the region of the body behind the first fourteen segments, the dorsal vessel acts merely as a channel for collecting and propelling the blood forwards. The ventral vessel is the chief distributing channel throughout the

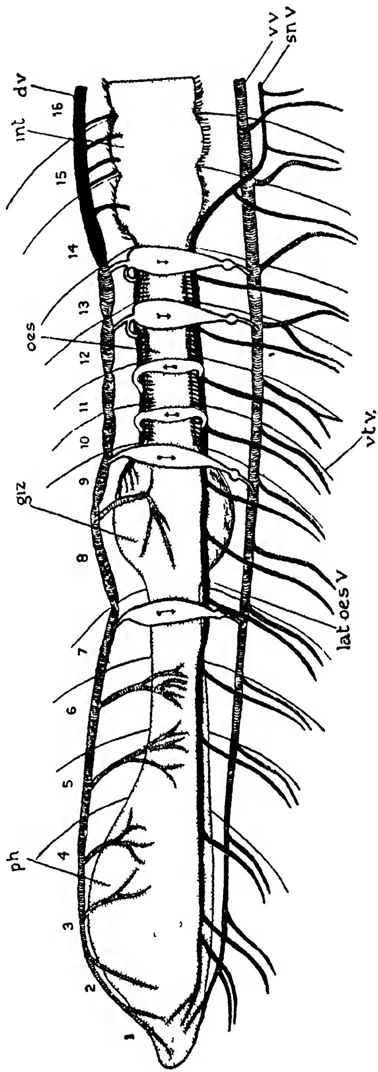


FIG. 89B.—A diagrammatic representation of the blood-vessels in the first sixteen segments, *d v*, dorsal vessel; *giz*, gizzard; *int*, intestine; *lat œs*, lateral œsophageal vessel, *œs.*, œsophagus, *ph*, pharynx, *sn v*, subneural vessels, *v v*, ventral vessel, *vt v*, vessel to the body-wall. Numerals indicate the segments. The "hearts" lie in the seventh, ninth, twelfth and thirteenth segments, and the "anterior loops" in the tenth and eleventh segments. (After Karam Narayan Bahl.)

body. Its branches supply blood to the body-wall, nephridia and other structures lying in the body-cavity, and by a short unpaired vessel in each segment directly to the wall of the gut. The blood is returned from these parts to the subneural and from that into the commissurals or directly to the commissurals, and thus gets back in either case into the dorsal vessel. The blood from the gut-wall is returned more directly through the dorso-intestinals.

In the first fourteen segments of the body, the circulation of the blood is on different lines from that in the rest of the body. The dorsal vessel, instead of functioning as a receiving channel, here becomes a great distributing trunk. It sends out blood into four pairs of rhythmically contractile " hearts," which are situated in the seventh, ninth, twelfth and thirteenth segments, and pump the blood into the ventral vessel. The dorsal vessel also supplies the blood, by paired branches, to the gizzard, the pharynx and the pharyngeal nephridia. The ventral vessel continues to be a distributing channel and supplies the body-wall, the integumentary nephridia, spermathecæ, seminal vesicles, ovaries, etc. It does not, however, supply blood to the gut, as the latter is in this region supplied by the dorsal vessel. The subneural vessel on entering this region bifurcates into two *lateral œsophageals* (Fig. 89 B, *lat.œs.v.*) which are running on the right and left of the alimentary canal, and attached to its walls in the region of the œsophagus. The blood from the gut, nephridia, and reproductive organs is returned to the lateral œsophageals. These empty into the main stream through the " anterior loops " situated in the tenth and eleventh segments, and the supraœsophageal vessel which extends from the tenth to the thirteenth segments, and communicates in its turn with the two posterior pairs of " hearts " situated in the twelfth and the thirteenth segments.

The blood returned to the lateral œsophageals is thus passed into the ventral vessel, or flows backwards into the subneural and passes through the commissurals into the dorsal vessel, in the region posterior to the fourteenth segment. The blood-vessels thus form a continuous though somewhat complicated circulatory system.

There is a series of small whitish bodies, known as *lymph-glands* (Fig 89, *b gl*), lying upon the intestine on either side of and close to the dorsal vessel. They are lobulated masses of peritoneal cells and are segmentally arranged, a pair in the twenty-sixth and every succeeding segment.

The red colour of the blood is due to *hæmoglobin* (p. 113), which is not, as in the frog, contained in red blood-corpuscles, but is dissolved in the plasma, in which, however, minute colourless corpuscles can be recognised. The function of hæmoglobin in the process of respiration has already been described (p. 152) ; but in the earthworm, as in many other lower animals, there are no specialised respiratory organs (lungs or gills), the necessary exchange of gases being performed by the entire surface of the body, the minute branches of the blood-vessels in the body-wall being only separated from the air by the single layer of epidermic cells—and even penetrating amongst the latter in the region of the clitellum: this is an exceptional occurrence, for, as we have seen, capillaries do not, as a general rule, extend amongst epithelial cells (compare, *e.g.*, Figs. 43–45).

Excretory System.—In discussing in a previous chapter the differences between plants and animals (p. 250), we found that in the unicellular organisms previously studied the presence of an excretory organ in the form of a contractile vacuole was a characteristic feature of such undoubted animals as Amœba and many other Protozoa. But the reader will have noticed that Hydra and its allies have no specialised excretory organ, waste-products being apparently discharged from any part of the surface. In the earthworm we

meet once more with an animal in which excretory organs are present, although, in correspondence with the complexity of the animal itself, they are very different from the simple contractile vacuoles of Paramœcium or Vorticella, and are more nearly comparable with those of the frog (p. 154).

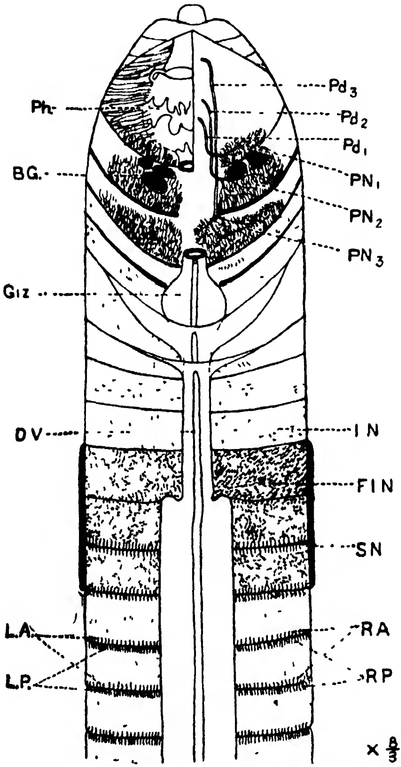


FIG. 90.—The general plan of the nephridial system in *Pheretima posthuma*. × 8/3
S.N. septal nephridia, R A, R P, L A, L P, right and left anterior and posterior series of septal nephridia, I N integumentary nephridia, F I N 'forests' of integumentary nephridia, P N_1, P N_2, P N_3, pharyngeal nephridia of the fourth, fifth, and sixth segments displayed after removing the septa between these segments, Pd_1, Pd_2, Pd_3 ducts of the pharyngeal nephridia; B G blood glands, Ph. pharynx; Giz gizzard; D V. dorsal vessel. (After Karm Narayan Bahl.)

The excretory organs in most kinds of earthworms are little tubes called *nephridia*, of which each metamere—with few exceptions—g e n e r a l l y possesses a pair, one on either side. You will remember that in the frog all the urinary tubules are connected together to form a pair of kidneys, each with a single duct communicating with the cloaca. In the common English earthworm (*Lumbricus*) and among other genera

cord. The brain consists of a pair of white pear-shaped swellings or *supra-pharyngeal ganglia* (Fig. 89, *c.g.*) situated on the dorsal side of the buccal sac where it is continued into the pharynx. The ventral nerve-cord is a longitudinal band extending along the whole middle ventral line of the body, internally to the longitudinal muscular layer, from the third to the anal segment, and slightly swollen in each segment. The brain is connected with the anterior end of the ventral nerve-cord by a pair of nervous bands, the *circumpharyngeal connectives* (Fig. 93, *com*), which pass respectively right and left of the pharynx and thus form a *nerve-collar.* In transverse sections (Fig. 88) the nerve-cord (*v.n.c.*) is seen to be composed of two longitudinal cords surrounded by a common sheath. This is due to the fact that during development there are two distinct laterally situated cords which gradually approach each other and fuse together in the middle line to form the double ventral nerve-cord of the adult.

It is to be noted that one division of the central nervous system—the brain—lies altogether above and in front of the enteric canal, the other division—the ventral nerve-cord—altogether beneath it ; and that, in virtue of the union of the two divisions by the circumpharyngeal connectives, the enteric canal perforates the nervous system. Both brain and cord are composed of delicate nerve-fibres and nerve-cells, the latter being situated in the ventral and lateral regions of the cord along its whole length, so that there is here hardly any distinction into ganglia and connectives, although the swellings are often spoken of as ganglia. Along the dorsal side of the cord, as seen in transverse sections, are three transparent tube-like structures, known as *giant-fibres,* the function of which is not known (Fig. 88). The whole cord is enclosed in a sheath consisting of connective-tissue and muscular fibres.

The peripheral nervous system consists of a number of nerves, both sensory and motor (p. 171), which arise from the central nervous system and supply the various parts of the body. From the brain a number of nerves are given off to the prostomium, and from each ganglionic enlargement two pairs of nerves can be traced into the body-wall, while between these enlargements one pair is given off which supply mainly the septa.

Comparing the nervous system of the earthworm with that of a medusa, it is important to notice the concentration of the central nervous system in the higher type, and the special concentration at the anterior end of the body to form a brain. When, again, we compare the central nervous system of the earthworm with that of the frog (pp. 28 and 163) several important points of difference are noticeable. In the former it lies freely in the cœlome, and, with the exception of the brain, is situated on the ventral side of the body; while in the frog it is enclosed in a neural canal and is dorsal in position. The brain of the frog is a complicated structure, and the whole nervous system is hollow, there being ventricles in the brain and a central canal in the spinal cord; while in the earthworm the brain consists merely of a pair of cerebral ganglia, and it and the ventral cord are solid.

The whole nervous system is capable of originating automatic action. It is a well-known fact that if the body of an earthworm is cut into several pieces each performs independent movements; in other words, the whole body is not, as in the higher animals, paralysed by removal of the brain (p. 182). There can, however, be little doubt that complete co-ordination, *i.e.*, the regulation of the various movements to a common end, is lost when the brain is removed.

The earthworm is devoid of organs of sight or hearing. It exhibits sensitiveness to bright light, which may be due to direct action on the central parts of the nervous system. The sense of hearing appears to be absent; but a faculty analogous to taste or smell enabling the animal to distinguish between different kinds of food is well developed. Groups of narrow sensory cells in the epidermis, which are most abundant on the prostomium and peristomium, have probably to do with this faculty.

There are two matters of general importance in connection with the structure of the earthworm to which special attention must be drawn.

Notice in the first place how in this type, far more than in Hydra, we have, as in the frog, certain definite parts of the body set apart as *organs* (p. 30) for the performance of particular functions: it is clear that differentiation of structure and division of physiological labour play a far more obvious and important part than in any of the lower organisms described in the four previous chapters.

Notice in the second place the vastly greater complexity of microscopic structure, the body being divisible into *tissues* (p. 125), each clearly distinguishable from the rest. We have epithelial tissue with its cuticle, muscular tissue, and nervous tissue, as well as blood and cœlomic fluid. One result of this is that, to a far greater extent than in Hydra, we can study the morphology of the earthworm, as we have done that of the frog, under two distinct heads: *anatomy* and *histology* (p. 110).

Regeneration.— Asexual reproduction does not take place normally in the earthworm, but it frequently hap-

pens by accident that a worm is cut into two or more parts. When this occurs, each end is able to reproduce the missing portion: this process is known as *regeneration* (compare p. 304).

Reproductive System.—The earthworm, like Hydra, is monœcious or hermaphrodite (p. 304), and besides the essential organs of sexual reproduction—ovaries and spermaries—which are, as in the frog, developed from certain parts of the cœlomic epithelium (p. 331), it possesses various accessory organs. The whole reproductive apparatus is situated in segments 6–21.

The *ovaries* (Fig. 94, *ov*), are a pair of minute bodies about 1 mm. in length, attached by their bases, one on either side, to the posterior face of the septum separating segments 12 and 13, not far from the nerve-cord. The proximal end of each ovary, nearest the stalk, is composed of a mass of undifferentiated cells of *germinal epithelium* (compare Figs. 67 and 68): nearer its middle, certain of these are seen to increase in size so as to be recognisable as young ova: while the distal end consists of a number of separate filaments, each of which resembles a string of beads and contains the ripe ova, each enclosed in a vitelline membrane and containing a large nucleus and nucleolus and a number of granules of food-yolk (p. 206). The eggs are discharged into the cœlome and are received into the female gonoducts or *oviducts* (Fig. 94, *ovd*)—two short tubes, each with a funnel-like mouth with much-folded margins, placed opposite the corresponding ovary. The oviducts perforate the next following septum (*i.e.*, that between segments 13 and 14) and converge to meet beneath the nerve-cord and open by a single minute aperture on the fourteenth segment in the mid-ventral line.

Certain sacs called *spermathecæ* (Figs. 89, *sp*, 94, *sp*, *th*)

also belong to the female part of the reproductive apparatus. Of these there are usually four pairs in this species

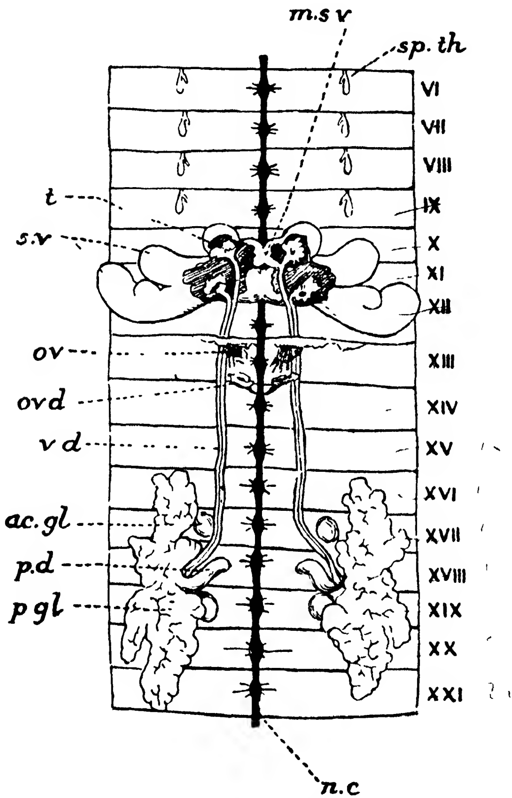


FIG 94 —Reproductive organs of *Pheretima posthuma*. (Modified from Lloyd) *ac gl* accessory glands; *m.s v* median seminal vesicle, *n c* nerve cord; *p d* prostatic duct; *p gl* prostatic gland, *ov* ovary, *ovd.* oviduct; *s.v.* lateral seminal vesicle; *sp th* spermatheca, *t.* testis; *v d.* vasa deferentia. Roman numerals indicate the respective segments.

situated in the sixth, seventh, eighth, and ninth segments, and opening to the exterior on the ventral surface in the

grooves between the fifth and sixth, sixth and seventh, seventh and eighth, and eighth and ninth segments respectively. Each spermatheca consists of a pyriform sac which is continued into a duct, from which a narrow diverticulum is given off. The function of these spermathecæ will be mentioned presently.

The earthworm possesses two pairs of minute white *spermaries* or *testes* lying in the median seminal vesicles, attached to the posterior face of the septum between the ninth and tenth, and tenth and eleventh segments respectively (Fig. 94, *t*). They are recognisable only in young worms, becoming atrophied in the adult. Behind each spermary, in the same segment, and also contained within the median seminal vesicle, is a ciliated *seminal funnel*, produced backwards through the septum next behind into a *spermiduct* or *vas deferens*. The two ducts of either side meet each other in the twelfth segment, and run backwards side by side in a somewhat irregular course on the body-wall till they reach the seventeenth segment, where they curve outwards to open into the prostatic duct just near its origin. The *prostates* or *spermiducal glands* (Figs. 89, 94, *p.gl.*) are a pair of large white glands of an irregular shape lying on either side of the intestine in the sixteenth to twenty-first segments. Each gland has a muscular duct which receives the vasa deferentia of its side; and the prostatic ducts of the two sides curve to open externally at the male genital pores on the eighteenth segments (Fig. 87, *m. g. p.*) In segments 17 and 19 are two pairs of accessory glands corresponding in position with the genital papillæ seen externally on these segments in series with the male genital pores. The function of the prostate and the accessory glands is not known.

The most prominent portions of the reproductive apparatus are certain large whitish bodies — the

sperm sacs or *seminal vesicles* (Figs 89, *l.s.v.*, 94, *s.v.*), which are very apparent in the adult worm as soon as the cœlome is cut open in this region. Of these there are three pairs, situated in segments 10–12. The cavities of the seminal vesicles are to be looked on as enclosed portions of the cœlome; and each of the pairs in segments 10 and 11 are joined together across the middle line and below the œsophagus by a median chamber, also cœlomic in origin, the *median seminal vesicle* (*m. s v*). The testes and funnels of the vasa efferentia, as already noted, are contained within these median vesicles, sometimes called testis-sacs.

The cells of which the spermaries are composed do not develop into sperms in the testes themselves, but pass into the seminal vesicles, where they undergo division into rounded masses of cells (*gametocytes*, compare p. 283) looking very much like a segmenting oosperm in the polyplast stage. Each of these products of division of the testicular cells becomes elongated, and gradually takes on the form of a sperm with a rod-like head and a vibratile tail (compare pp. 206 and 305). When set free, the sperms pass into the spermiducts through the ciliated funnels.

It is well known that many flowers (the reproductive organs of higher plants) contain the generative cells of both sexes, enclosed within the ovules and anthers respectively; yet in very many cases self-fertilisation does not occur owing to contrivances of various kinds for its prevention. It has been proved in numerous instances that cross-fertilisation—*i.e.*, the impregnation of the ovum in one individual by the male cell of another—is of great importance in keeping up the strength and vigour of the plant from generation to generation. The same is true amongst animals; and though in some

monœcious forms, such as the Hydra, there is no special arrangement for the prevention of self-impregnation if the male and female gametes of the same individual ripen at the same time, in others, such as the earthworm, the ova are always fertilised by the sperms from another individual.

This is effected in the earthworm in the following way. Two individuals, their anterior ends pointing in opposite directions, become applied together by their ventral surfaces and attached to one another in this position by a viscid secretion from the clitellum. The sperms are then passed from the male apertures of one into the spermathecæ of the other individual, and the two worms afterwards separate The clitellum then secretes a tough chitinous tube or *cocoon*, which forms a broad ring round the body in this region, and which is gradually slipped forwards by the worm wriggling back out of it. As it passes over the apertures of the oviducts and spermathecæ, ova and sperms (the latter derived from the other individual) are passed into it, as well as albumen secreted by certain glands present in this region. When the worm has entirely withdrawn itself from the cocoon, the latter closes up at the ends in virtue of its elasticity, and the eggs, after fertilisation, undergo segmentation.

The cells of the polyplast soon become differentiated into an outer ectoderm, and an inner endoderm enclosing the enteron, which communicates with the exterior by the blastopore (compare p. 212). A mesoderm (pp. 213 and 319) is then developed, and each layer gradually gives rise to the corresponding parts in the adult animal, much as in the frog, except that the nephridia are apparently derived in the first instance from the ectoderm (compare p. 221); the mesoderm undergoes segmentation, the cœlome appearing in it as a cavity (p. 215)—or

rather as a series of cavities, one in each segment. The young worm is then hatched, and it is to be noticed that it passes through no metamorphosis (p 12).

Systematic Position.—There are a number of different kinds of animals commonly known as " worms," but many of these (*e g.*, the parasitic worms in the duodenal loop of the frog, liver-flukes, tapeworms, etc.) are very different from the earthworm in structure, and are placed in several different phyla. The earthworm is a member of the phylum Annelida, which also includes a number of other worms living in the sea and in fresh water, as well as the leeches, etc. In all these the body is elongated, bilaterally symmetrical, and divided into metameres ; the integument is soft , the mouth is anterior, and the anus posterior ; there is usually an extensive cœlome ; and the nervous system and nephridia are essentially similar to those of the earthworm. The class *Chætopoda* ("bristle-footed" worms), in which the earthworms and their fresh-water and marine allies are included, receives its name from the fact that all its members are provided with cuticular setæ, which in the order to which the marine forms belong (*Polychæta*) are usually long and of varied forms, and are much more numerous than in the earthworms and fresh-water worms, which constitute the order *Oligochæta*.

NEREIS.

Nereis[1] as a type of the Polychæta.—The oligochætous earthworm is, as we have seen, adapted to a subterranean mode of life, and feeds on decaying organic matter. For comparison, it will be instructive to consider the external form and mode of life of a predaceous marine polychætous worm, called *Nereis*, various species of which are of common occurrence between tide-marks

[1] The internal anatomy of this animal is omitted.

on the sea-shore, under stones, and among sea-weed in all parts of the world, sometimes swimming actively through the water. The worm varies considerably in colour even in the same species.

In shape (Fig. 95) the body, which may be about 7 or 8 centimetres in length, is long and narrow, approximately cylindrical, somewhat narrower towards the posterior end. A very distinct *head*, bearing eyes and tentacles, is recognisable at the anterior end; the rest is divided by a series of ring-like narrow grooves into a corresponding series of metameres, which are about eighty in number altogether; and each of these bears laterally a pair of movable muscular processes called *parapods*, provided with bundles of setæ.

The head is constituted by the prostomium and the peristomium (p. 327). The former bears on its dorsal surface four large, rounded *eyes*, in front a pair of short cylindrical *tentacles*, and further back a pair of somewhat longer, stout appendages or *palps*. The peristomium, which has some resemblance to the segments of the body, though wanting the parapods, bears laterally four pairs of long, slender, cylindrical tentacles; on its ventral aspect is a transversely elongated aperture, the aperture of the mouth. The segments of the body differ little in external characters from one another throughout the length of the worm and there is no clitellum; each bears laterally a pair of parapods, which in the living animal are usually in active movement, aiding in creeping or acting as a series of oars for propelling it through the water. When one of the parapods (Fig. 96) is examined more attentively it is found to be biramous, consisting of two distinct divisions—a dorsal, which is termed the *notopod* (*noto*), and a ventral, termed the *neuropod* (*neuro*). Each of these is further subdivided into several lobes, and bears

a bundle of setæ, lodged in a sac formed by invagination of the epidermis and capable of being protruded or retracted and turned in various directions by muscular fibres in the interior of the parapod. In each bundle there is, in addition to the ordinary setæ, a stouter, straight, dark-coloured seta (*ac*), the pointed apex of which projects only a short distance on the surface; this is termed the *aciculum*. The ordinary setæ are exceedingly fine but stiffish, chitinous rods, of which two principal kinds are recognisable; both have a terminal blade articulating with the main shaft of the seta by a distinct joint. On the dorsal side of the parapod is a short, cylindrical, tentacle-like appendage, the *dorsal cirrus* (Fig. 96, *dors. cirr*), and a similar, somewhat shorter, appendage, the *ventral cirrus* (*vent. cirr*), is situated on its ventral side. The last segment of the body, the *anal segment*, bears posteriorly a small rounded aperture, the *anus;* this segment is devoid of parapods, but bears a pair of appendages, the *anal cirri*, similar in character to the cirri of the ordinary segments, but considerably longer.

FIG 95 —*Nereis dumerilii* Natural size (From Parker and Haswell's *Zoology*, after Claparède)

On the ventral surface near the bases of the parapods there is in each segment a pair of very fine nephridiopores (p. 342), through which the sperms possibly pass to the exterior, there being no special genital duct. Dorsal pores are also wanting.

The mouth leads into a wide buccal cavity, which is

continued back into a pharynx. In the pharynx are a number of very small, dark brown, chitinous *denticles*, which are very regularly arranged. The posterior part of the pharynx has very thick walls composed of bundles of muscular fibres which are concerned in the movements of a pair of laterally placed chitinous *jaws*. The anterior part of the alimentary canal is capable of being everted, as a *proboscis*, until the jaws are thrust forth and project freely, so that they can be brought to bear on some small living animal or fragment of animal matter, which is thus seized and swallowed.

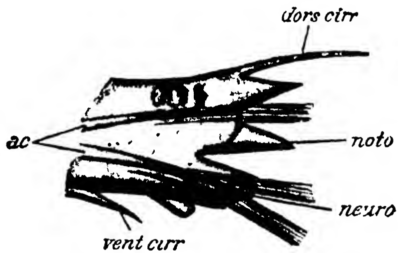


FIG 96 —*Nereis dumerilii* A single parapod (× about 25) *ac* aciculum, *dors cirr* dorsal cirrus; *neuro* neuropod; *noto* notopod, *vent cirr* ventral cirrus, (From Parker and Haswell's *Zoology*, after Claparède)

In correspondence with its different mode of life, Nereis is much better provided with sense-organs than is the earthworm. The tentacles and palps, as well as the cirri, are probably organs of touch; and as we have already seen, four eyes are present on the prostomium.

Almost without exception, the Polychæta further differ from the Oligochæta in being diœcious, and in passing through a metamorphosis The segmented oosperm gives rise to a minute, more or less oval larva known as a *trochosphere*, which swims by means of cilia arranged in circles round the body, and gradually undergoes metamorphosis into the adult.

Classification.—The phylum **Annelida** consists of the following classes:—

Class **Chætopoda.** Annelids provided with bristles or setæ.

Sub-class **Oligochæta.** Those with no definite "bristle stumps" (parapodia), but with only scattered bristles on each segment. No distinct head. Chiefly land or fresh-water forms. *Pheretima.*

Sub-class **Polychæta.** Those with definite parapodia, each usually bearing many long bristles. A definite head is present, bearing eyes and tentacles. Special filamentous gills are often developed. Chiefly marine forms. *Nereis.*

Class **Hirudinea.** Annelids destitute of bristles. Leeches.

PRACTICAL DIRECTIONS

EARTHWORM

Select a large earthworm, and after noting its movements and mode of progression, kill by immersion in spirit for a few minutes and then place in a dish and let the tap ru on it for a short time.

A. **External Characters.**

1. Note :—*a*. The form and colour of the body a division into *metameres* · *b* the anterior end, term in the *prostomium* and followed by the *peristomium* *clitellum ;* and *d* the last or *anal segment.*

2. If the worm be drawn through the fingers the *setæ* will be felt : examine with a lens and c position and arrangement on each segment.

3. Make out the following apertures : *c* *b*. the *anus ;* *c* the *dorsal pores* (p. 334) ; *d* tures of the *spermiducts*, with thicken eighteenth segment (as also the genital seventeenth and nineteenth segments) aperture of the *oviducts* on the anterior *f*. four pairs of openings of the *spermat* between segments 5–9.

Sketch the animal from below, and make a separate enlarged diagram of the ventral surface of segments 13–20.

B. **Dissection.**

I. Take a freshly-killed worm in the left hand, and carefully insert the point of the fine scissors into the integument about one-third of the way along the body, close to the middle dorsal line Place a drop of the *cœlomic fluid* which exudes on a slide, add a drop of salt solution and cover. Examine with the low and high powers, and note the structure and movements of the *amœboid corpuscles.* Sketch at intervals (The small granules you will notice in the cœlomic fluid are derived from the broken down yellow cells of the intestine)

II Continue the cut forwards to the prostomium, keeping *very* slightly to one side of the median dorsal line, and taking care that the point of the scissors does not penetrate deeper than the integument: note the iridescent *cuticle.* Place the animal in a dish with just enough water to cover it, and carefully insert a pin between the integument and the yellow intestine on either side, near the posterior end of the incision, so as to expose the *cœlome* · note the *septa* connecting the body-wall with the intestine Then insert more pins, so as to expose the cœlome and enteric canal up to the anterior end, *taking especial care not to tear the ventral parts* *of the septa* and to stretch the animal longitudinally as much s possible The pins should be fixed obliquely (and not rtically) with the head of the pins directed outwards, so t there may be some working space between a pair of site pins It will be better to fix them in definite n segments, so that they will serve as a guide to the n of the organs and save the trouble of counting hen the specimen has been dissected. Then note Figs 89 and 94) :—

'ateral seminal vesicles—three pairs of large white egments 10–12, united together by anterior r *median seminal vesicles* situated ventral to s in segments 10–11.

canal and its subdivisions :—*a. buccal sac ;* *ullet ; d gizzard ; e.* portion of the *gullet* ed by the seminal vesicles) ; and *f intestine,* yer of *yellow cells,* and giving off a pair of he twenty-sixth segment

l-vessel, containing red blood and in the he body giving off branches to the

enteric canal; the large rhythmically contractile "hearts" connecting the dorsal with the ventral (sub-intestinal) vessel. the latter will be seen subsequently.

4 Numerous fine tubules covering the anterior and posterior faces of all the septa behind the fourteenth segment, the *septal nephridia*, and others covering the inner surface of the body-wall. the *integumentary nephridia*, imparting a whitish, fluffy appearance to the septa and the body-wall.

Add a little methylated spirit to the water in your dissecting dish and sketch your dissection.

5. The *ovaries* Examine segment 13 closely, being very careful not to injure its contents, and the ovaries may then be seen under a lens projecting backwards into this segment, one on either side just external to the œsophagus They can be recognised by their shape, and by the fact that they hang freely into the cœlome, as can be seen by touching them with a seeker. Carefully seize the septum between segments 12 and 13 with the small forceps, and cut around the attachment of an ovary so as to remove it. Stain with methyl-green or magenta, and mount in glycerine Note the mass of undifferentiated cells at the proximal, attached end of the ovary, and the gradual development of the ova towards the distal, narrower end. Examine the *ovum*, and observe the nucleus, nucleolus, and granules of food-yolk. Sketch the ovary.

(The *oviducts* are not easy to make out in dissections)

6. The pyriform *spermathecæ* (usually four pairs, s p. 348) in segments 6–9

III. Tease out a small portion of a sperm-sac, stain magenta, and mount in glycerine. The following sta the development of the sperms can then be made c *a*. the *sperm-mother-cells* or *gametocytes* (developed spermary) in different stages of division; the pr division, each with a nucleus, and arranged ir peripheral row, the central mass of protoplasm undivided; *b*. the gradual elongation of these and *c*. the conversion of each into a *sperm* forming the rod-like "head," and the prot rise to the delicate "tail"; *d*. free sperms (in the spermathecæ; some of them sho fresh and their movements noted) Sl stages.

It is difficult to make out the two pai the *spermiducts* by dissection, and the studied by examining transverse sect

IV. 1. Note the small *suprapharyngeal ganglia* or *brain* (Fig 89) on the dorsal side, and then cut through the anterior part of the pharynx just behind the brain Carefully remove the enteric canal, noting as you do so the *ventral* (*subintestinal*) *blood-vessel* The *nervous system* (Fig 93) will now be exposed Observe again the paired cerebral ganglia, from which arise a pair of *connectives*, forming a small *nerve-ring* or *collar* around the pharynx, and continuous ventrally with the *ventral nerve-cord*, consisting of fused lateral halves and extending along the whole length of the ventral body-wall, passing through a perforation in each septum, and expanding slightly in each segment, so as to form ganglionic swellings Three pairs of nerves are given off in each segment. Sketch

2. Remove a portion of the cord, and note the *sub-neural vessel*

V. Remove the integument covering one complete segment, and spread it flat with the outer surface, showing a continuous row of *setæ*, uppermost. Mount in water and examine (compare Fig 87, C) Sketch.

C. **Transverse Sections.**—For the preparation of these, keep a worm for a few days in coffee-grounds or small pieces of blotting-paper moistened with water, in order that the gritty contents of its intestine may be replaced by a soft substance which will not blunt the razor. Kill the worm, it off a small piece about ¼ inch in length from the region the intestine, and fix, stain, and cut into transverse ions as directed on p 145 Examine a section (com- Fig 88) with the low power, and note —

1. The thin *cuticle*, *b* the *epidermis*; *c* the very thin · *d* the *setæ*, with their sacs, if your section passes one or more of them

muscles of the body-wall *a* The external *circular* d *b*. the thicker *longitudinal layer*, appearing in transverse section Note that the muscles

ne and *peritoneal membrane*

ne, with its dorsal *typhlosole*. It is lined r of columnar cells (*enteric epithelium*), a thin muscular and connective-tissue to this, again, are the elongated and , which are especially abundant in the

al, and subneural blood-vessels and ry ducts.

6 The ventral *nerve-cord*, just internal to the longitudinal muscular layer. It is enclosed in a muscular and connective-tissue sheath. Along the dorsal side are three clear-looking "*giant fibres*." Observe the *nerve-cells* along the cord ventrally and laterally, the *nerves* coming off from the cord, and the symmetrical halves of which the cord is composed

7 The *nephridia* —these will be seen cut through in various planes

The thin *septa* will be cut through in different directions. and their relations are therefore not easily seen in sections, note the circular and radial muscular fibres in them. Sketch the section, and then put on the high power and work through §§ 1–7 again. Notice that the cavities in the sections of the nephridia are *intra-cellular*. Sketch as many details as possible.

D. Sift some earth and look for *cocoons*.

NEREIS

Note —1 The *head*, consisting of (*a*) *prostomium* , its *tentacles*, *palps*, and *eyes*, and (*b*) *peristomium* wit tentacles ; also the *proboscis*, *mouth*, and lateral chit *jaws*.

2. The *metameres* of the body, each with a (*a*) *dorsal* and *ventral cirri*, and (*b*) lobed *parapods*, divided into *notopod* and *neuropod*, and bearing a chitinous *setæ*

3. The *anal segment* with *anal cirri*, but no p

Carefully cut out an entire parapod and m slide (Fig 96). Note the two bundles of *setæ* of an *aciculum* and of numerous jointed setæ forms The structure of the setæ will be r out if separated from one another with entire parapod is treated with a solution 5 grammes of potassium hydrate in 100

*

CHAPTER VI

CHARACTERS OF THE PHYLUM ARTHROPODA—THE PRAWN —THE COMMON COCKROACH—CLASSIFICATION

IF we examine and compare, even casually, a Prawn, a Scorpion, a Centipede, and a Wasp, we see at once that these resemble each other in certain broad features, ınd differ from the animals we have studied so far. 'hey all have the body consisting of a number of more less distinct segments; the body is covered in all by ırd, or at least tough, cuticle; they all possess a m of appendages—feelers, jaws, legs, etc, which odified for the performance of different functions lifferent animals mentioned and in the different the body of the same animal, though in every ıre *jointed* and the different segments of each are covered by a hard or tough integument, v itself. These external features, together oints in the structure and arrangement of gans, are characteristic of the phylum *Arthron*, joint, and *pod-os*, a foot). In he phylum includes more species than of the animal kingdom put together, together mainly into four large fied by one of the four familiar ve.

ıffers from the rest in being an by means of branchiæ or gills

The others are terrestrial, and take in air directly by a system of air tubes. The Prawn is a representative of the class *Crustacea*, the Scorpion of the class *Arachnida*, the Centipede of the class *Myriapoda*, and the Wasp of the class *Insecta*.

THE PRAWN [1]

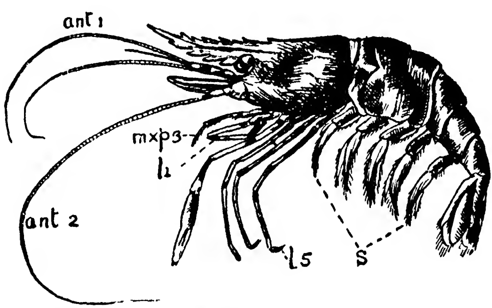
The class *Crustacea* comprises a very large number of Arthropods, the great majority of which are inhabitants either of fresh- or of salt-water. Among the more generally known members of this class may be mentioned the Prawns, Shrimps, Lobsters and Crayfish, Crabs and Hermit-crabs, etc. As an example, the common fresh-water Prawn, *Palæmon*, found in slow running streams and ponds in most places, may be studied, but where there is any difficulty in obtaining them, specimens fro the sea of the genus *Penœus*, which can be obtain from the Government Fisheries Station at Ennur, may substituted. The following description applies r especially to Palæmon, but will serve the purpose essential respects for Penœus as well.

External Features.—It will be noticed at o the Prawn, like the Earthworm, is a bilater metrical animal, the right and left halves o being exactly alike. The Prawn also res Earthworm in being metamerically segme it differs from the latter in its having constant number of segments or metam by the fact that certain of these are m united with one another. The resul segments is that two distinct regior in the body—an anterior *cephaloth* *abdomen* (Fig. 97). Instead of tl the Earthworm or of Nereis, t

[1] The internal anatomy of th

enclosing crust of exoskeleton, formed of thickened and chitinous cuticle; and instead of the short unjointed parapodia of Nereis, there is a series of variously modified appendages—feelers, jaws, legs, etc.—which, like the body itself, are enclosed in a hard, jointed exoskeleton, their movable segments being termed *podomeres*.

The cephalothorax is unjointed and is covered by a cuirass-like structure, the *carapace*; and the abdomen is divided into distinct segments, movable upon one another in a vertical plane. The cephalothorax is



he Common Prawn (appendages of one side only shown). *ant.* 1 anten- *t.* 2, antenna, *mxp* 3, third maxilliped, l_1 *to* l_5, five walking legs, *S* ts. (After Lulham)

ı two regions, an anterior—the *head*, and a e *thorax*, by a transverse depression, the ·. The carapace is developed from the ·al regions of both head and thorax; it is f the thorax, where it forms a flap or *gill-* each side, separated from the actual ırrow space ın which the gills are ıder part of the body is bent region of the third abdominal

·m the ventral surface. Both

trunk and appendages are covered with a sort of shell formed of *chitin* (p 328), which is hard and elastic.

The *abdomen* is made up of seven segments: the first six of these are to be considered as metameres in the sense in which the word is used in the case of the earthworm. The shell surrounding each has a ring-like form, presenting a broad and arching dorsal region or *tergum* (Fig 98), which is continued downwards into lateral processes, the *pleura* (*p*), a flattened ventral

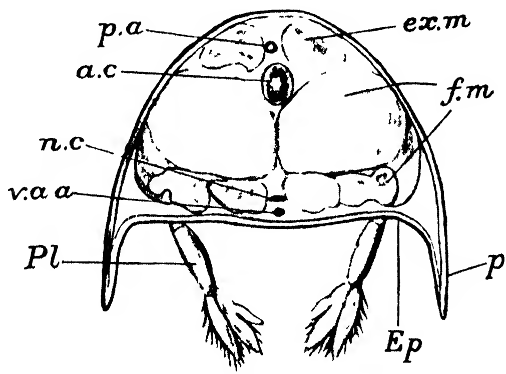


FIG 98 —Transverse section through abdomen of a Prawn *a c* *exm* dorsal or extensor muscles of the abdomen, *Ep* epime flexor muscles of the abdomen, *n c* nerve cord, *p* plei abdominal artery, *Pl* pleopod, *v.a a* ventral abdominal art

region or sternum, and between the pc ment of each appendage and the pleur (*Ep*). The seventh division of the pointed *telson* (Fig. 97). All sev covered by a transparent, flexible, ch and are united to one another by sof the first segment is similarly joine

It has been stated that the a movable upon one another in a whole abdomen can be *exten*

flexed or bent under the cephalothorax, the segments are incapable of movement from side to side This is due to the fact that, while adjacent segments are connected dorsally and ventrally by flexible articular membranes, they present at each side a *joint*, placed at the junction of the tergum and pleuron, and formed by a little peg-like process of one segment fitting into a depression or socket in the other

Owing to the presence of the carapace the *thoracic region* is immovable, and shows no distinction into segments either on its dorsal (tergal) or lateral (pleural) aspect. But on the ventral surface the sterna of the horacic segments are clearly marked off by transverse ooves, and the hindmost of them is slightly movable. ogether eight thoracic segments can be counted.

he *head* exhibits no segmentation dorsally: the ı of the five segments composing it, though fused er, can still be counted. The ventral surface of d is, in fact, bent upwards, so as to face forwards of downwards. The cephalic region of the is produced in front into a large median ne, the *rostrum*: immediately below it is a which spring two movably articulated odies, the *eye-stalks*, bearing the eyes at

–Attached to the soft cuticle between lateral portions of the exoskeleton are endages, one pair to each segment; dified in different regions of the body n they have to perform (Fig. 99). ce the long feelers attached to the legs springing from the thorax, odies arising from the sterna of e convenient to begin with the

The first six segments of the abdomen bear each a pair of small appendages, the swimming feet or *pleopods* (Fig. 98, *Pl*). A typical pleopod (Fig 99, 16) consists of an axis or *protopodite* having a very short proximal and a long distal podomere, and bearing at its free end two plates, fringed with setæ, the *endopodite* and *exopodite*. These appendages act as fins, moving backwards and forwards with a regular swing, and probably aiding in the animal's forward movements. The first pleopod in the male is markedly different from that in the female. The endopodite is somewhat larger and the endopodites of the two sides approach towards the median line to form a spout-like structure which serves to transfer the spermatophores

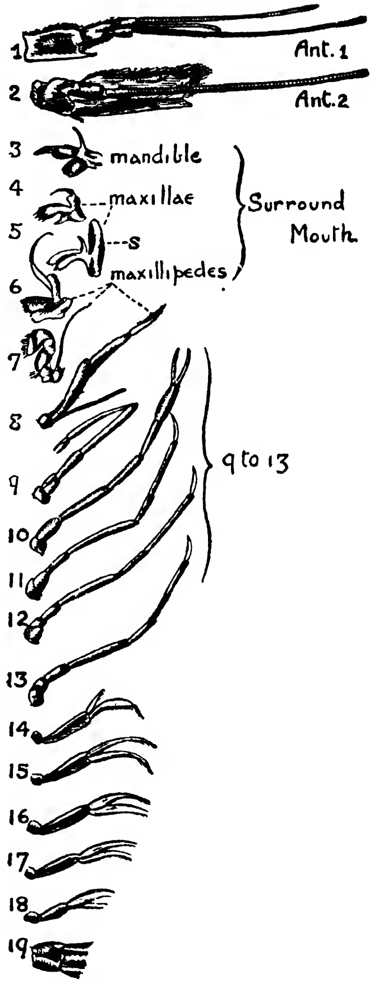


Fig. 9
ren
arr

to the body of the female. The sixth pair of pleopods (19) are very large, both endopodite and exopodite having the form of broad, flat plates: in the natural position of the parts they lie one on either side of the telson, forming with it a large five-lobed *tail-fin*: they are therefore conveniently called *uropods* or tail-feet. The telson itself bears no appendages.

The thoracic appendages are very different. The five posterior segments bear long, slender, jointed *legs* (9–13), vith which the animal walks: the first two pairs of 'hese terminate in claws or *chelæ*, and hence called *elipeds* (Fig. 99, 9–10). The three anterior thoracic ments bear much smaller appendages, more or less ıke in form, but serving as jaws: they are distin-ed as *maxillipedes* or foot-jaws.

structure of these appendages is best understood nsideration of the *third maxilliped* (Fig. 99, 8). all the parts of a biramous appendage. The te consists of two segments. From the second ses an inner three-jointed endopodite, and an nented exopodite. From the outer side of the of the protopodite arises a small lamellar *ipodite*. The first two pairs of maxillipedes lified and their basal joints aid in the d. In the *second maxilliped*, the exo-than in the third, and the endopodite, consists of five segments and is per-wards. In the *first maxilliped* the roduced inwards as flattened plates, ınsegmented flattened and pointed opodite is a long, slender and There are two leaf-like epipodites he protopodite.

fer from the third maxilliped ı having no exopodite: in the

fifth or last the epipodite also is absent. The first two of them have undergone a curious modification, by which their ends are converted into pincers or *chelæ*: the fourth segment of the endopodite (sixth of the entire limb) is produced distally so as to form a claw-lik projection, against which the terminal segment bite The first leg is relatively thin and delicate, and is turr forward on the top of the maxillipedes, lying dou over just behind them, whilst the second is the la of all and bears the efficient pincers with whic animal catches its prey.

The head bears a pair of *mandibles* and two *maxillæ* in relation with the mouth, and in fron aperture a pair of *antennules* and of *antennæ*. most appendage of the head is the *second ma* leaf-like appendage, its protopodite being c lobes, while the exopodite is modified into a oval plate known as the scaphognathite (*s*), a current of water to pass into the gill c thus serves as an important accessory org tion. The *first maxilla* (4) is a very sma neither exopodite nor epipodite. The *n* large, strongly calcified body, toothed edge, and bearing on its anterior bor jointed, feeler-like structure, the *pa* segments of which represent the endo segment, together with the mandib podite.

The *antenna* (2) is of great le long as the whole body. It cor podomeres, the fifth or last c flexible, many-jointed struc from the second segment spr *squame*. It is fairly obviou segments represent the protop

with the feeler, the endopodite, and the squame the exopodite. On the ventral side of the basal segment of the protopodite is a conical elevation on which the duct of the excretory organ opens.

The *antennule* (1) has an axis of three podomeres ιding in three many-jointed feelers; two of them ιting in a common base represent the inner ellum, which bears the usual relation to the flagellum. These are sometimes considered as ponding to the endopodite and exopodite. But in e other limbs, as we have seen, the exopodite from the second segment of the axis, and the ities are that there is no exact correspondence the parts of the antennule and those of the appendages. The first basal segment is as e other two taken together. It is expanded l to lodge the eye on its dorsal side.

lks, already noticed, arise just above the an- are formed each of a small proximal and segment. They are sometimes counted serially homologous with the antennæ e more properly to be looked upon as sses of the prostomium.

ιe Prawns creep about on the bed of the shoots of the aquatic plants by 'king legs," but when swimming these little, if at all. A gentle forward ι be attained by the movement of hen startled, the Prawn will dart hrough the water. This it is ently and suddenly lashing its ts body, which drives the water ιction causes the body to jerk

s of respiration are in the

form of gills, contained in a cavity lying below the side flaps of the carapace, which should be cut away on one side, so as to expose them (Fig. 100). There will then be seen seven little white, elongated plates, decreasing rapidly in size from the largest—attached to the body-wall just above the last walking leg—to the very small anterior one attached to the base of the second maxilliped. These white plates are the gills in which the blood circulates, and in order to keep the blood aerated it is necessary that a constant current of water should pass over

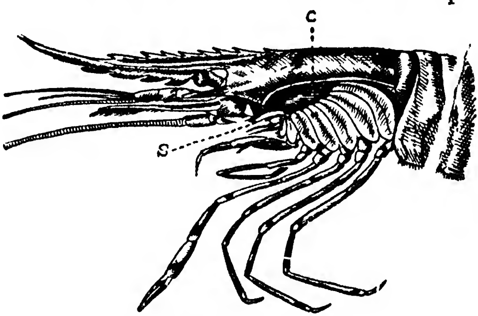


FIG. 100 —View of a Prawn with one side of the carapace cut away, the gills
c, cut edge of the carapace. *s*, scaphognathite, or plate of the
(After Lulham)

them. That this occurs can be demonstrat
a little carmine or other easily visible
powder into some pond water with a livi
the current will carry it in at the back m
of the carapace, and out at the fro
current is maintained to some degre
movement of the creature through t
is at rest by the movement of the
or scaphognathite attached to
(Fig. 100, *s*); this plate, by its mo
out of the gill chamber in fro
water to enter from behind.

Reproduction.—The sexes are distinct, the fertilised eggs are laid and are carried by the female attached to some of her swimmerets until they hatch; they are afterwards protected in a broad pouch made by the ending forward of the abdomen.

The larval Prawns which hatch out are very unlike the lt; they are little, soft, transparent creatures with rudiments of the thoracic walking legs, although e appendages in front of these are well developed; domen also, though fully segmented, has at first ndages. These larvæ are known as Zooea larvæ. nmature larva develops, it goes through a series it, and when it has acquired its final form and eleton, the moult is still continued periodically r the further growth of its body.

The Cockroach.

secta comprises the Cockroaches, Grass- nflies, Houseflies, Mosquitoes, Butter- with their many allies. The class is a ne, and includes a larger number of other group of the animal kingdom. nsect, like that of a Crustacean, is rs a series of pairs of jointed appen- k is covered with a chitinous cuticle, n. Like the body of the Crustacean, divisible into certain regions. In ns are always three in number, h abdomen. The head does not ntation in the adult, and bears of *mandibles*, and two pairs of sts of three enlarged segments, ventral surface a pair of legs, ear on the dorsal surface a

pair of wings. The abdomen consists of a varying number of segments. It bears no appendages except at the posterior end, where a pair of jointed feeler-like processes are found.

As a type of this class we shall study the common cockroach, known as *Stylopyga orientalis*, which is said to have been originally a native of tropical Asia. It is not quite so common, however, in many places in India, though specimens can generally be found inhabiting the

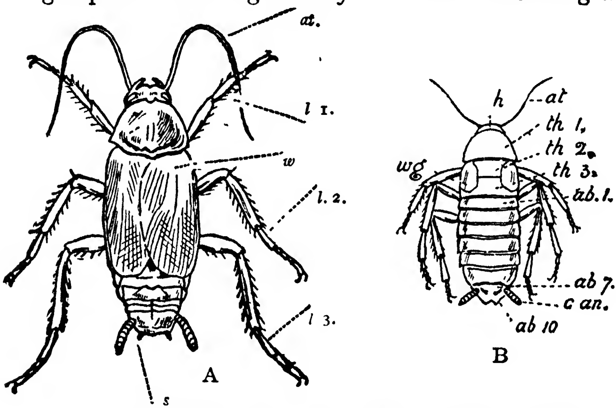


FIG 101 —*Stylopyga orientalis*, dorsal view. A male; B female. *at* antenna, *ab* 1 to *ab* 10, abdominal terga, 8 and 9 are concealed by 7 in the female, but are visible, though small, in the male, *c an* anal cerci, *l* 1 to *l* 3 thoracic legs, *s* styles, *th* 1 prothoracic tergum; *th* 2 mesothoracic tergum, *th* 3 metathoracic tergum; *w* anterior wing, *wg* vestige of the anterior wing in the female (A after Shipley and Macbride, B. after Borradaille)

vegetable markets. Specimens of a closely allied form known as *Periplanata americana* are also found. In the former species the wings and wing-covers of the female are rudimentary, and in the male do not reach to the end of the abdomen. In *P. americana* both sexes are winged, and the wings and wing-covers are longer than the body. Both are nocturnal animals, and are often found in human dwellings, but hide themselves in corners and crevices during the daytime.

Head.—The Cockroach is divided into regions and bears the appendages as mentioned above. The head is flattened and placed at right angles to the axis of the body. Looked at from the front, it has a pear-shaped outline, with the narrow end directed downwards towards the mouth. The front and sides of the head are covered over by strong chitinous plates, *viz.*, two *epicranial plates* above (Fig. 102, *ep*), a *clypeus* (*clp.*)

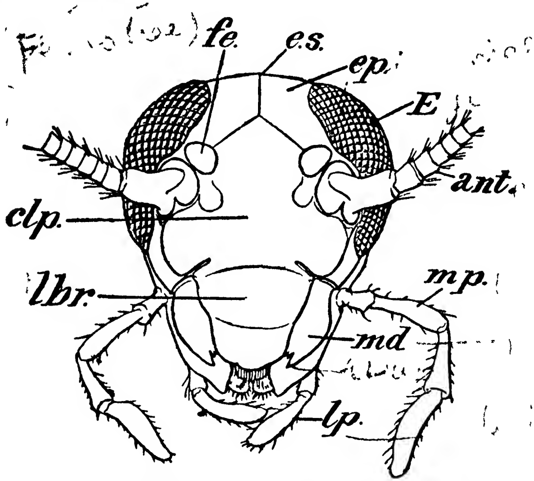


FIG 102 —Head of *Stylopyga orientalis* seen from the front *ant* antenna, *clp* clypeus; *E* eye, *ep* epicranium, *es* epicranial suture, *fe* fenestra; *lbr* labrum, *lp* labial palp, *md* mandible, *mp* maxillary palp. (After Bourne)

forming the lower part of the face, and two *genæ* at the sides below the eyes. Hinged on the lower edge of the clypeus is a movable flap, the *labrum* or upper lip. On each side of the head is a large *compound eye* (*E*) which appears as a black reniform area, the surface of which is marked off into a great number of minute hexagonal facets. The antennæ (*ant.*) are a pair of long, slender, many-jointed, whip-like structures, arising close to the

inner curve of each eye, on the front of the head. During life they are stretched downwards as if to try the ground on which the creature moves, or held aloft as if to test the air. To the inner and upper side of each antenna is a small circular area of white colour, covered by soft cuticle. These areas are called the *fenestræ* (*fe.*). The mouth is situated on the lower edge of the head covered in front by the labrum. At the sides of the mouth are situated the first and second pairs of mouth appendages, known as the mandibles and the first maxillæ, and a third pair fused together in the middle line forms a plate called the labium, and completes the boundaries of the mouth behind. Each *mandible* (Fig. 103, *A*) is a stout, single-jointed structure with no palp, and with a toothed inner margin which bites against the corresponding part of its fellow. The *first maxilla* (*B*) consists of a protopodite of two joints, known as the cardo (*ca.*) and stipes (*st.*), a five-jointed exopodite known as the maxillary palp (*p p.*), and a double endopodite consisting of an inner pointed *lacinia* (*la*) and an outer softer *galæ* (*ga.*) The *second* pair of *maxillæ* are constructed on the same plan as the first, but the protopodites and the endopodites are fused together. The first joint of the fused protopodite is called *sub-mentum* (*s.m.*), the second is the *mentum* (*m.*), and the partially fused endopodites constitute the *ligula*. Each half of the ligula consists of an inner *lacinia* (*la.*), and an outer *paraglossa* (*ga.*) corresponding to the galea of the first maxilla. The exopodites or *labial palps* (*p.p.*) are three-jointed, and are raised on a projection of the mentum.

The head is joined to the thorax by a slender *neck* covered with a soft cuticle in which are developed a number of hard, chitinous plates or sclerites.

Thorax.—The three segments of the thorax are known

as *prothorax, mesothorax,* and *metathorax,* and each of these is covered by a dorsal *tergum* and a ventral *sternum.* The tergum of the first is the largest and projects forwards to conceal the neck. Each segment bears a pair

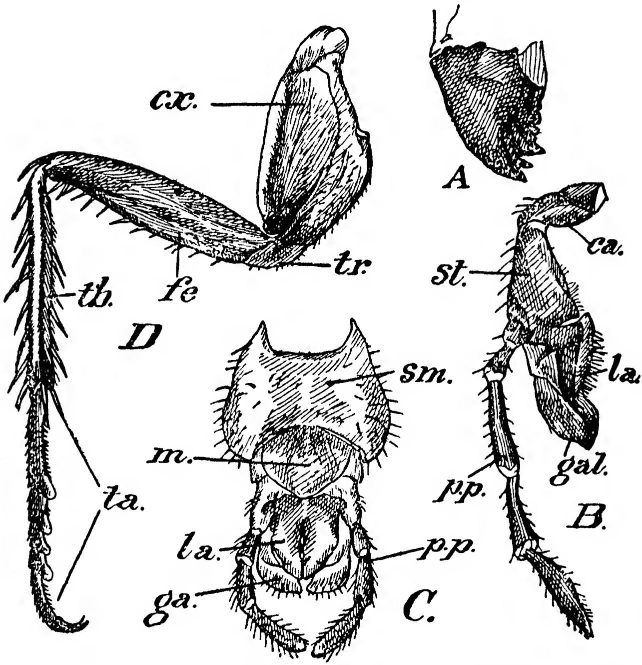


FIG. 103.—A B C. Mouth and appendages of *Stylopyga.* Magnified D. Second thoracic leg, drawn to a smaller scale than the mouth parts.
A. Mandible, *B* first maxilla, *ca.* cardo; *st* stipes; *la* lacinia, *gal* galæ, *p p* maxillary palp; *C* fused second maxillæ or labium; *sm.* submentum, *m* mentum, *ga* paraglossa, corresponding to the galea; *la* lacinia, *p p* labial palp; *D.* second thoracic leg, *cx.* coxa; *tr.* trochanter; *fe.* femur; *tb.* tibia, *ta* tarsus. (After Bourne)

of legs (Fig. 103, *D*) consisting of a stout basal joint, the *coxa* (*cx.*), a very small *trochanter* (*tr.*), an elongated stout *femur* (*fe.*), a more slender *tibia* (*tb.*), and a *tarsus* (*ta.*) composed of five short joints terminating in a very

small movable piece which bears a pair of claws. The tibia and tarsus bear numerous bristles which are used in cleaning the body, and the terminal claws are used in climbing. The names of the various joints were given as the result of fanciful and misleading comparison with the parts of the vertebrate limb, with which, however, they are not homologous. The mesothorax and metathorax bear each a pair of wings jointed to the anterior corners of their respective terga. The wings are membranous expansions of the skin strengthened by a network of ridges or nervures. The anterior pair are dark-coloured and horny, and in a state of rest conceal the dorsal surface of the animal behind the prothorax. One of them slightly overlaps the other, and the two together form a protective cover to the more delicate posterior wings; hence they are generally known as wing-covers or elytra. The posterior pair of wings are thin and membranous and constitute the effective organs in the rare flight of the cockroach. At rest they are folded like a fan and concealed by the elytra.

Abdomen.—The abdomen consists of ten segments, each with a tergum and a sternum joined at the sides by soft cuticle. The eighth and the ninth terga are narrow and tucked under the seventh and are not readily seen unless the animal is artificially stretched. In the male *Stylopyga orientalis*, however, portions of these terga remain uncovered, and are generally visible from the surface without disturbing the adjacent parts (Fig. 101, *A*). The tenth tergum projects backwards beyond the extremity of the body and is cleft into two lobes. The abdomen is broader in the female than in the male, and the seventh sternum is boat-shaped and projects backwards, completely concealing the eighth and ninth sterna and forming the floor of a roomy pouch or cavity in which the egg-case is formed. In

the male also the eighth and the ninth sterna are largely concealed by the seventh. A pair of many-jointed, tapering *anal cerci* (*c. an.*), probably homologous with other appendages, emerge below the tenth tergum in each sex, and, in the male, the ninth sternum bears a pair of slender unjointed *anal styles* (Fig. 101, *A, s.*).

In the soft tissue between the tenth tergum and the last visible sternum, at the posterior end of the body, is situated the anus, and, below it, the single genital-pore. The anus is supported by a pair of thickened plates, called the *podical plates*, and the genital orifice is surrounded by a complicated set of processes known as the *gonapophyses*, which are concerned with the process of copulation and egg-laying.

On the sides situated in the soft membrane connecting the terga and sterna are ten pairs of *stigmata* or openings leading to the respiratory tubes. Two of these are larger and situated on the sides of the thorax, one between the prothorax and mesothorax and the other between the mesothorax and metathorax, and the remaining eight are situated between the lateral margins of the tergum and the sternum, at the anterior end of each of the first eight abdominal segments.

Digestive Organs.—On removing the skin from the dorsal surface, a body-cavity is exposed which is not a cœlome, but a hæmocœle, as the blood does not remain within a system of closed tubes but flows out into spaces existing between the various organs contained within the cavity. The cavity is largely filled by a loose white tissue known as the fat body, which surrounds the various internal organs. The alimentary canal (Fig. 104) is remarkable for the great extent of the stomodæum (fore-gut) and proctodæum (hind-gut) which are formed as invaginations of the anterior and the posterior ends of the embryo respectively, and are therefore lined by

cuticle, and the small extent of the mesenteron or mid-gut which alone is formed from the primitive alimentary tract of the embryo. The fore-gut consists of a *buccal cavity*, the posterior wall of which is raised into a conical fleshy tongue or *lingua*, leading into a narrow *gullet* passing through the neck, and expanding into a large thin-walled pyriform sac, the *crop* (*cr.*), which extends through the thorax and partly into the abdomen, and is followed by a short *gizzard* (*giz.*) with thick muscular walls. The inner lining of the gizzard is raised up into six prominent longitudinal folds covered by chitinous plates which can be approximated in the middle line and act as a grinding apparatus. Behind these cuticular teeth are six small elevations covered with setæ which act as a strainer, and allow only finely divided particles of food to proceed further. The chitinous lining of the gizzard projects backwards in a spout-like form into the mid-gut. The mid-gut or *mesenteron* (*m.g.*) is short and narrow, and is lined by endoderm, being thus the only part of the alimentary canal where absorption can take place. The mid-gut is produced at its anterior end into seven or eight finger-like *hepatic cæca* (*hp. c.*) which secrete a digestive fluid. The mesenteron, the limit of which is marked by the insertion of the *Malpighian tubules*, is succeeded by the hind-gut or proctodæum, a long, coiled tube, which is divisible into a narrow *ileum*, a wider *colon* (*cn.*), and a sac-like *rectum* (*rm.*) which opens to the exterior by the anus.

Lying along the crop on each side are a pair of diffuse *salivary glands* (*sal. g.*) and between each pair a bladder-like *salivary receptacle* (*sal. r.*). The ducts of the two glands of each side join, and ducts of both sides unite to form a median duct. This is joined by another median duct formed by the union of the ducts of the receptacles. The common duct so formed opens into

the floor of the mouth in the angle between the tongue and the lower lip. The saliva converts starch into sugar. The secretion of the hepatic cæca emulsifies fats and converts proteins into peptones The products of digestion are passed, after absorption, into the blood, which everywhere bathes the alimentary canal, and through that agency carried to all parts of the body.

Organs of Circulation.—The blood is kept in circu-

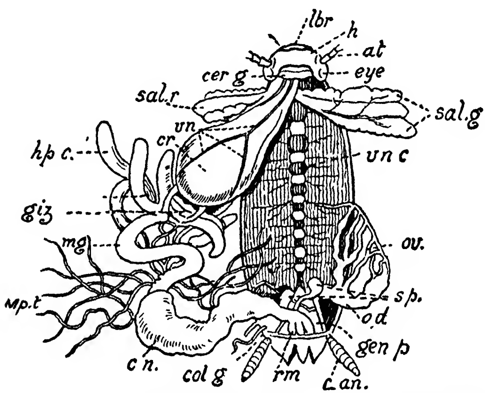


FIG 104 —A female Cockroach, *Stylopyga*, dissected from the dorsal side. (After Shipley and Macbride)
at antenna, *c. an.* anal cerci, *cer. g* cerebral ganglia, *cn* colon, *col g* colleterial gland, *cr* crop, *eye,* eye, *gen. p.* genital pouch, *giz.* gizzard, *h,* head, *hp c.* hepatic cæca, *lbr.* labrum, *m g* mesenteron, *Mp t* Malpighian tubules, *od* oviduct, *ov* ovary, *rm.* rectum, *sal. g.* salivary gland, *sal r.* salivary receptacle, *sp.* spermatheca, *vn.* visceral nerves, *v. n. c* ventral nerve cord.

lation by a contractile vessel lying in the mid-dorsal line close under the skin, which is known as the *heart.* It extends through the whole length of the thorax and abdomen, and is divided into thirteen chambers corresponding to the number of segments of the body in these regions. Each chamber is narrowed in front, and this narrower portion projects into the chamber next in front and is guarded by a valve which permits the blood to flow in a forward direction only. At the hinder

end of each chamber is a pair of ostia or holes through which the blood enters from the pericardium, and valves prevent the blood being forced out of the ostia. The heart lies in a pericardial sinus formed by a horizontal membrane stretched across the body-cavity This membrane is perforated by a number of small openings through which the blood passes from the hæmocœle to the pericardial sinus. Periodic contraction of certain muscles attached to the sides of the pericardial septum, called the alary muscles, produces a flattening of the septum, thus enlarging the pericardial sinus and causing an inflow of blood into it from the rest of the hæmocœle.

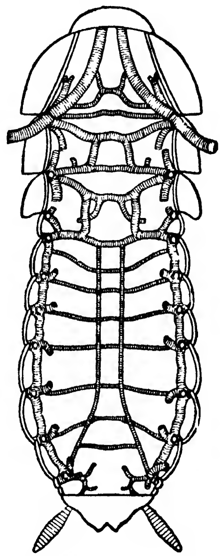


FIG 105—View of the arrangement of the principal trunks of tracheal system (After Miall and Denny)

Anteriorly the heart is continued forwards as the aorta, which opens by a trumpet-shaped orifice into the hæmocœle, and the blood pours out of it and bathes all the organs of the body. It thus absorbs the food from the alimentary canal and carries it to all parts of the body, superfluous fat is stored in the fat body, and waste nitrogenous materials are carried from the organs to the Malpighian tubules, by which they are passed out of the body. The blood is colourless and contains amœboid cells. Unlike what is usual in other animals, its respiratory function is at a minimum, air being carried to all organs by a system of respiratory tubes or tracheæ.

Respiratory Organs.—The respiratory system consists of branching tubes or *tracheæ* (Fig. 105), which open

to the outer air by ten pairs of stigmata, whose position has been noted before. The tracheæ, being full of air, present a glistening white appearance when the cockroach is dissected under water. The larger branches have a definite and symmetrical arrangement. There are dorsal arches running up towards the heart and ventral arches descending towards the nerve-cord. These arches are connected with one another by longitudinal trunks. The finer branches become smaller and smaller until they become veritable capillaries which penetrate every tissue. Seen under the microscope (Fig. 106) the tracheæ show a spiral thickening of the chitinous lining, which helps to prevent them from collapsing. Respiration is effected by the alternate arching up and flattening of the abdomen, which by increase or diminution of its volume secures an alternate inrush and expulsion of air from the tracheæ.

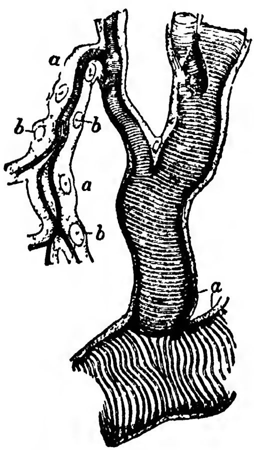


FIG. 106.—Microscopic appearance of a portion of a trachea *a* cellular wall; *b* nuclei (From Packard, after Leydig.)

Excretory Organs.—The excretory organs are the Malpighian tubules, which are extremely fine, long blind tubes, 60–80 in number, arranged in six bundles which open into the beginning of the narrow portion of the proctodæum, from which they are outgrowths. They float in the blood, winding about amongst the abdominal viscera (Fig. 104, *Mp. t.*). Their cavities often contain uric acid, which is separated from the blood by the glandular epithelium lining the tubules and passes out of the body through the intestine.

Nervous System.—The nervous system is on the same general plan as that of the other segmented Invertebrata which we have considered so far. There is a pair of large *supra-œsophageal ganglia* or *brain* (Fig. 104, *cer. g.*) giving off *commissures*, which encircle the œsophagus and unite below in a *sub-œsophageal ganglion*. Together, these occupy a considerable portion of the cavity of the head. The supra-œsophageal ganglia supply paired nerves to the eyes and to the antennæ, and the sub-œsophageal ganglion supplies the mandibles and both pairs of maxillæ. From it two cords (*v. n. c.*) pass backwards and bear three pairs of ganglia in the thorax and six pairs in the abdomen, the last of the series being large, and supplying nerves to its own and other posterior segments of the body. The alimentary canal is supplied by a visceral nervous system which receives nerves from the circum-œsophageal commissures and the brain. The principal *visceral ganglion* lies on the dorsal side of the crop.

The sense organs include the large compound *eyes* (Fig. 102), the antennæ, which are tactile and olfactory, the maxillary palps, anal cerci, and various bristles which are all tactile.

The compound eyes of the cockroach occupy a large, irregular, oval space on each side of the head (Fig. 102, *E*). Each is marked off into a great number (about 1,800) of minute facets. Each facet is the outermost of a series of parts, some refractive and some sensory, which form one of a mass of radiating rods or fibres. The facets are transparent, biconvex, and polygonal, often, but not quite regularly, hexagonal. The facets (Fig. 107, *Co. F.*), taken together, are often described as the cornea. Beneath the cornea we find a layer of crystalline cones (*Cr.*), each of which rests by its base upon the inner surface of a facet, while its apex is directed

inwards towards the brain. The crystalline cones are transparent, refractive, and coated with dark pigment.

Behind each cone is a nerve-rod (rhabdom) (*Rm.*), which, though outwardly single for the greater part of its length, is found on cross-section to consist of four components (rhabdomeres); these diverge in front and receive the tip of a cone, which is wedged in between them. The rhabdom is invested by a protoplasmic sheath, which is imperfectly separated into segments (retinulæ) (*Rl.*), corresponding in number with the rhabdomeres. To the hinder end of the retinulæ are attached the fibres of the optic nerve. As to the way in which the compound eye renders distinct vision possible, it is generally believed that each element of the compound eye transmits a single impression of greater or less brightness, and the brain combines these impressions into some kind of picture, a picture like that which could be produced by stippling—that is to say, there is "mosaic vision."

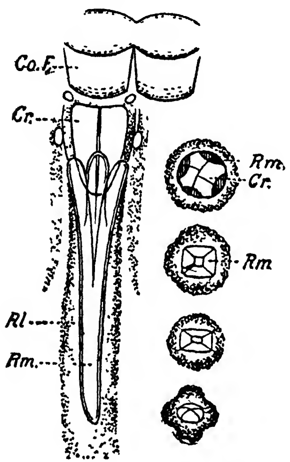
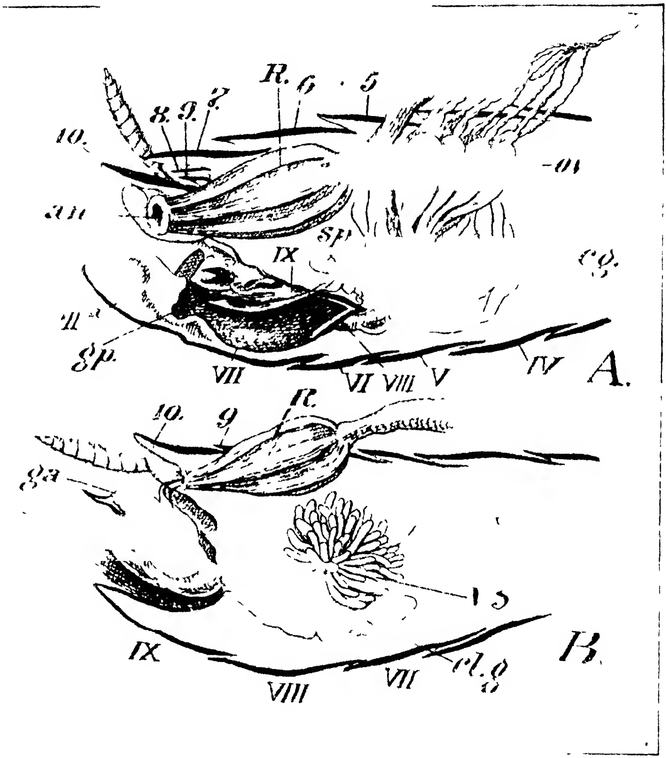


FIG 107—One element of the compound eye of the Cockroach × 700 *Co F* corneal facets, *Cr* crystalline cones, *Rm* nerve-rod (rhabdom), *Rl* retinula of protoplasmic fibrils To the right are transverse sections at various levels (From Miall and Denny, after Grenacher)

Organs of Reproduction.—The sexes are separate. In the male, the paired *testes* are no longer functional in the adult condition, and as they become reduced in size, it is with difficulty that they can be recognised from the fat body in which they are imbedded. In the young males, however, they can be readily found as two small

bunches of small spherical vesicles of a transparent appearance (Fig. 108, B, *t*,), lying beneath the fifth and



[illegible] ans of the Cockroach, as seen in dissections from the right side [illegible] ans of the right side have been removed.
A, Female, B, Male
A, Female, *an*, anus, [illegible] and, *gp*, gonapophyses; *or*, ovary, *R*. rectum, *sp*., spermatheca, [illegible] terga, *IV–IX*, sterna
B, Male, *cl. g*., conglobate gland, *ga*, gonapophyses, *R*, rectum; *st*., anal styles; *t*., testis; *v.s*, vesicula seminalis; 9–10, terga; *VII–IX* sterna. (After Bourne)

sixth abdominal terga, one on each side of the body, and discharging their contents into two narrow *vasa deferentia*. These vasa deferentia lead backwards to a

conspicuous organ, the so-called *mushroom-shaped gland* which consists of two short saccular vesiculæ seminales (*v.s.*) lying side by side and bearing at their anterior ends a dense tuft of finger-shaped diverticula. Posteriorly the seminal vesicles unite to form a tube, the *ductus ejaculatorius*, which opens into the genital pouch by the male pore. A gland of doubtful function, known as the conglobate gland (*cl.g.*), lies below the ductus ejaculatorius and opens into it. The complex apparatus of hooks and plates surrounding the genital pore has been referred to already.

In the female, there are a pair of *ovaries* (Figs. 104 and 108, A, *ov.*) situated in the hinder part of the abdomen. Each consists of eight tubes, which show swellings caused by a row of ova, and at its anterior end the tapering tubes unite to form a thread which passes forwards till it gets lost in the fat body. Posteriorly the ovaries communicate by short and rather wide *oviducts* with a very short median uterus, which opens into the genital pouch by a slit-like aperture through the eighth abdominal sternum. On its under side the uterus receives the duct of a much-branched *colleterial gland* (Fig. 104, *col. g.*, and Fig. 108, A, *cg.*), and just above the opening of the uterus into the genital pouch is the opening of a small tubular *spermatheca* (*sp.*) which is filled with spermatozoa received from the male during copulation. During their descent the ova increase very much in size, being distended with food-yolk, and bulge out the walls of the ovarian tubes so that the latter look like strings of beads.

After they are laid in the genital pouch they are fertilised by spermatozoa poured out from the spermatheca, and these fertilised eggs are surrounded by the secretion of the colleterial glands, which hardens into the egg-capsule or *cocoon*. Sixteen ova, corresponding to the number of the ovarian tubes in the two ovaries,

are packed together in an egg-capsule, which is carried about for some days by the female, half protruding from its genital pouch, and finally deposited in some sheltered place, preferably near some convenient supply of food for the young when hatched out.

When the young ones come out of the cocoon they are white in colour and bear dark eyes, but the integument soon thickens and becomes dark. They have no wings, but in other respects they resemble the adult, and thus there is no metamorphosis such as occurs in the butterflies and many other insects. The casting of the skin or ecdysis takes place a number of times, and wings appear at the last moult.

Metamorphosis.—Metamorphosis is a very characteristic feature in the life-history of many insects. From the egg hatches out a creature which differs markedly from the adult of the species and lives an independent life. This is known as a *larva*. We have already come across an instance of a larva in the tadpole of frog. The larvæ of insects are specially unlike the adult in those cases in which the food and habits of the two are different. In such cases the larval form, which is always wingless, and may also be legless, as in the grubs of bees or maggots of flies, is retained until growth is complete, the growth being accompanied by a series of skin moults. Then the full-grown larva may enter upon a resting, quiescent stage, known as the *pupal stage.* In this stage the creature is generally motionless and ceases to feed, while certain important changes take place, leading to the perfecting of the special organs. When this is complete, the skin is cast off for the last time, and the winged adult creature, or *imago,* emerges. Such a series of changes, including a quiescent pupal stage, is known as a *complete metamorphosis.*

Life-history of a Gnat.—Metamorphosis which does not

occur in the cockroach can be readily noticed in the case of the common gnat, *Culex pipiens*. After mating, the female makes her way to water, in a ditch or rain-water tub, perhaps, and there lays her eggs on the surface, two or three hundred of them. As they are laid she arranges them with her hind legs and glues them together, side by side, making a little floating "raft" of eggs (Fig. 109).

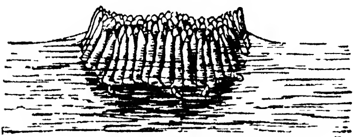


FIG 109 —The Gnat (*Culex pipiens*) Raft of eggs floating in the water (After Lulham)

After two or three days, the eggs hatch, and from each emerges a small, transparent larva, which at once begins to swim actively in the water. After the rains, myriads of these larvæ are found in practically every roadside ditch or other collection of rain-water, and the further life-history can be easily watched if a small quantity of water containing some of these larvæ is brought home in a glass bottle or jar. These larvæ, though able to swim so rapidly, when undisturbed will remain for a long time floating motionless in a vertical position, head downwards, at the surface of the water (Fig. 112), with a small respiratory tube (Fig. 110, *r*.) projecting obliquely upwards to the surface, from near the posterior end.

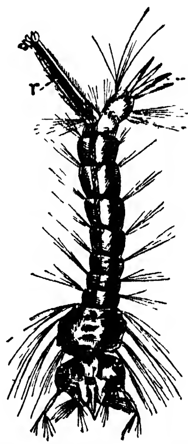


FIG 110.—Larva of *Culex pipiens* *r* respiratory tube, *p*, swimming organ (After Lulham)

In a fortnight or so, the larva moults its skin for the third or fourth time, and at the last moult changes its

shape completely, and becomes a *pupa*. In this condition it floats with its head upwards, and the rudiments of the eyes, wings, and appendages are clearly visible through the pupal skin which covers the big rounded mass at the front end. The head end being uppermost, the pupa breathes through two little trumpet-shaped tubes (Fig. 111, *r*.) on its head. The pupa does not feed, but, unlike the pupæ of most other insects, it is not always quiescent. If disturbed, it at once darts down in the water, and rises to the surface again soon after. The tail is provided with a pair of flaps which are used in swimming. After a few days, when the body of the imago has been perfected within, the skin splits along the back between the two air trumpets, and the perfect insect begins to emerge. The head and thorax push up first into the air, and then the legs and wings are carefully withdrawn.

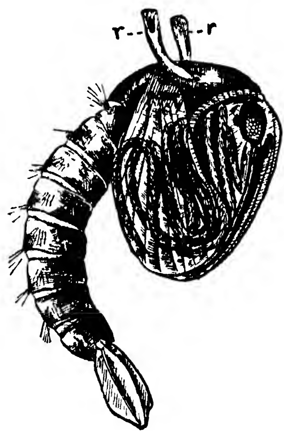


FIG. 111 —Pupa of *Culex pipiens* *r* respiratory tubes (After Lulham)

It has been mentioned in a previous chapter (Part II, Chap. III) that the common gnat, or *Culex*, does not convey the parasities of malaria from man to man, but that the spotted winged mosquito belonging to the genus *Anopheles* is responsible for carrying on that nefarious trade. It is of some importance therefore to be able to recognise the latter from the former. In the adult stage they are easily recognisable from one another by their characteristic posture when at rest. Culex has both the anterior and posterior ends of its body near the wall or the object

on which it is resting and has thus earned the appellation of being "hunchbacked," while Anopheles sits with the posterior end of its body directed away from the wall (Fig. 112); furthermore, it does not hold its posterior pair of legs so high in the air, and on closer examination shows a number of dark spots on each wing.

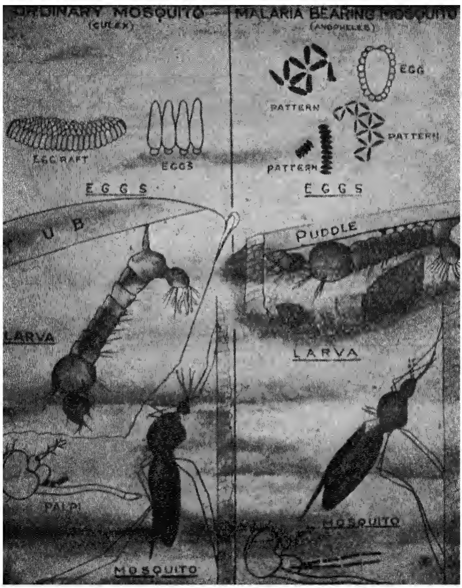


Fig. 112 —Stages in the life-history of *Culex* and *Anopheles* compared.

The *eggs* of Anopheles can be recognised by the fact that they are not laid in raft-like masses, are spindle-shaped, and lie separately and horizontally on the water. The *larvæ* (Fig. 112) also lie horizontally on the surface, and have a very short forked air tube. The pupæ are very similar to those of Culex.

Classification.—The phylum **Arthropoda** consists of the following classes among others :—

Class Crustacea.—Arthropoda possessing two pairs of feelers (antennules and antennæ) and three pairs of jaws. These as well as other limbs are typically biramous With few exceptions they are aquatic creatures breathing by means of gills or through the general surface of the body. **Prawns, Crabs, etc.**

Class **Myriapoda.**—Including Centipedes and Millipedes.

Class **Insecta.**—Arthropods, in which the body is divided into three distinct regions, viz., head, thorax, and abdomen. The head bears one pair of antennæ and three pairs of jaws. The thorax consists of three segments and bears three pairs of legs and usually two pairs of wings. Breathing is carried on by air tubes or tracheæ. The class is divided into a large number of orders, distinguished from each other by the number and the texture of the wings, by the modification of the mouth-parts, by the nature of the metamorphosis, and by the form and habits of the larva and pupa.

The more important of these orders are :—

1. *Aptera.*—Wingless insects known as Spring-tails and Silver-fish.
2. *Orthoptera.*—Cockroaches and Grasshoppers.
3. *Neuroptera.*—May-flies, Dragon-flies, &c.
4. *Coleoptera.*—Beetles.
5. *Hymenoptera.*—Ants, Bees, Wasps, &c.
6. *Hemiptera.*—Bugs, Lice, Plant-lice, &c.
7. *Diptera.*—All two-winged flies, including House-flies and Mosquitoes.
8. *Lepidoptera.*—Butterflies and Moths.

Class **Arachnida.**—Including Spiders and Scorpions.

PRACTICAL DIRECTIONS

PRAWN

If a living specimen is obtainable, note the *cephalothorax, abdomen, jointed appendages,* and *exoskeleton,* as well as the mode of walking and swimming. Kill with chloroform (p 31), or if living specimens are not obtainable examine the preserved ones. Owing to limitations of time, only the external features might be studied.

A. **External Characters.**

1. Note the cephalothorax and abdomen, and that the abdomen consists of seven movable segments or *metameres*. Examine the ventral side of the cephalothorax, and note that it also is composed of a number of segments, all fused except the ventral part of the last.

2. Examine the third or fourth abdominal segment closely, and note that it is connected with the segments in front and behind by a sort of peg-and-socket joint on either side, and that the chitinous exoskeleton at the joints is soft and pliable, forming an *articular membrane*, while elsewhere it is calcified. Distinguish between the dorsal convex *tergum*, the ventral *sternum*, the *pleuron* projecting downwards on either side from the tergum, and the *epimeron* between the point of attachment of an appendage and the pleuron Note also that the hinder part of the body is bent downwards.

3. Examine the appendages of the same segment: they are attached to the sterna, near the pleura, by articular membranes. Each consists of a basal or proximal portion —the *protopodite*, to which two distal, many-jointed parts are attached, an inner *endopodite*, and an outer *exopodite*. The cuticle covering the segments of the limb, or *podomeres*, is more or less thickened and chitinous, and the distal segments are covered with feathery *setæ*.

4. The second to the sixth abdominal segments are essentially similar to one another except as regards the appendages of the sixth segment. The sixth abdominal appendages are very large, and, together with the *anal segment* or *telson*, form the *tail-fin*. The first abdominal segment is smaller than the others and its appendages are peculiarly modified in the male (p 367).

5. The cephalothorax is reckoned as consisting of a *prostomium* and 12 metameres, which are completely fused dorsally and laterally, forming a large chitinous shield—the *carapace*. Thus the entire number of segments is 20 (prostomium + 18 metameres + telson).

6. Note :—*a*, the transverse *cervical groove* on the dorsal surface of the carapace, extending forwards laterally and forming the boundary between the *head* (prostomium + 4 metameres) and the *thorax* (8 metameres); *b*, the two longitudinal *branchio-pericardial grooves* on the tergal region of the thoracic portion of the carapace: the part of the exoskeleton between these covers the heart, and the part below each groove forms a large plate, the *gill-cover*, at the side of the thorax; *c*, the *rostrum* and movable *eye-stalks*.

7. Note the following apertures: *Median*—*a*, the *mouth*, on the ventral surface of the head, between the jaws; *b*, the *anus*, on the ventral side of the telson: *Paired*—*c*, the *auditory aperture*, on the dorsal side of the basal joint of the smaller feeler or antennule; *d*, the *renal aperture*, on a conical ventral elevation of the basal joint of the larger feeler (antenna); *e*, the *genital aperture*, in the male on the basal joint of the last thoracic leg, and in the female on the last thoracic leg but two.

B. **The Appendages.**—Remove the appendages on one side, beginning with the last, one by one, cutting through the articular membrane with a scalpel, and then taking hold of the basal joint with the forceps and pulling the appendage away. Work through the description on pp. 367–370 and sketch typical appendages from each region. Note the delicate *paragnatha* behind the mouth and the *labrum* in front of it.

C. **Respiratory Organs.**

1. Carefully cut away the left gill-cover with scissors, and fix the animal under water on its right side, so as to expose the left *gill-chamber* containing the feathery-looking *gills*. The inner wall of the chamber is formed by the proper wall of the thorax, and the chamber is open behind and below. In front of the gills is a groove, in which a flattened plate (see p 371) works backwards and forwards during life, driving the water out in front, and causing fresh water to enter from behind.

D **Sensory Organs.**

1 *Tactile organs*. Snip off some setæ from the body or appendages, and examine under the microscope. Sketch.

2. "*Olfactory*" *organs*. Examine the outer feeler of the antennule under the low power, and note the tufts of spatula-like "*olfactory*" *setæ* on the ventral surface. Sketch

3. "*Auditory*" *organ* (*statocyst*). Carefully cut away the convex ventral side of the basal segment of the antennule

with scissors, so as to expose the statocyst. Cut this out and place it on a slide, carefully removing the muscles surrounding it, as well as the setæ around its aperture. Note the contained grains of sand, and then wash them away. Stain with magenta and mount in glycerine, flattening the sac out with a cover-glass. Note that the sac is an involution of the integument lined by cuticle, and that it contains simple jointed *sensory setæ* of various sizes, arranged in rows, and that branches of the antennulary nerve run up the stem of each seta. Sketch.

4. *The eyes.* Remove one of the eye-stalks, and note the apparently black, uncalcified, oval portion of the cuticle (*cornea*) at its distal end Strip this off, and note that it is transparent. Then wash off any pigment which may have come away with it and mount in water Observe the *corneal facets* Then cut the eye-stalk into two longitudinal halves with a knife, and examine with a lens under water. Note the *optic nerve* entering the stalk, and enlarging to form the *optic ganglion*, from which a number of bodies (*ommatidea*) radiate outwards to the corresponding facets of the cornea. The ommatidea are separated from one another by pigment Sketch.

Examine longitudinal sections of the eye-stalks, decalcified and prepared as directed on p 145, and note in detail the above parts. Each ommatideum lies beneath the corresponding corneal facet, and is made up of an outer *vitreous body* or *crystalline cone*, and an inner *retinula* formed of sensory cells and enclosing a transversely-striated, spindle-shaped, refractive body or *rhabdome*, and closely connected with the optic ganglion. Note also the *pigment* between the ommatidea. Sketch.

COCKROACH

In a living specimen kept in a glass vessel observe its external form and habits, noting more particularly the position of its head and legs, and the way it uses its long feelers (*antennæ*) and the *maxillary* and *labial palps*. Feed it with pieces of bread and notice the lateral movements of its jaws. Also watch the rhythmic movements of the abdomen by which respiration is effected. Kill the animal by pouring two or three drops of chloroform on it, or by dropping it into boiling water.

A. External Characters.

1 Extend the wings, and note that the body is divided into *head, thorax,* and *abdomen,* the thorax consisting of three segments and abdomen of ten segments, the more posterior ones being telescoped within each other. The *head* bears the *antennæ* and the *compound eyes* ; the *prothorax* bears the first pair of legs, the *mesothorax*, anterior pair of wings and the second pair of legs, and the *metathorax*, the posterior pair of wings and the third pair of legs ; and the *abdomen* bears a pair of terminal appendages, the *cerci*, and in the male a pair of anal *styles* in addition. Sketch the specimen from the dorsal side, with the wings extended

2. Note the *mouth* opening on the ventral surface of the head, behind the *labrum* and between the *jaws*. At the hinder end of the body beneath the tenth abdominal tergum is the *anus*, and on either side of it are the small *podical plates*. In the female note that the *seventh abdominal sternum* is produced into a large boat-shaped structure, and the hinder sterna are completely hidden by it The *genital aperture* is placed ventral to the anus. On each side of the body are the *stigmata* or respiratory apertures, one between the prothorax and mesothorax, the second between the mesothorax and metathorax, and the remaining ones between the lateral margins of the tergum and the sternum, at the anterior end of each of the first eight abdominal segments

3 Holding the specimen between the thumb and the second finger of your left hand, examine the anterior surface of the head, and note the *epicranium, clypeus, compound eyes, antennæ, fenestræ, genæ, labrum, mandibles, first maxillæ*, and *second maxillæ* fused to form the *labium*

4. With the scissors cut off the labrum, and cutting close to the base of each of the mouth appendages, remove the mandibles, first maxillæ, and labium and mount them in glycerine. Examine under the low power of a microscope, and sketch In the case of the first maxilla, note the protopodite consisting of *cardo* and *stipes*, the endopodite consisting of *lacinia* and *galea*, and the exopodite, or *maxillary palp* In the labium note the *submentum, mentum, ligulæ, paraglossæ*, and the *labial palp* (p. 375).

5. Remove one of the thoracic legs, and note that it consists of the following parts : *coxa, trochanter, femur, tibia,* and *tarsus*, the latter terminated by a pair of claws Sketch.

B. **Dissection.**

Fix the animal in a dissecting dish with its ventral surface downwards by inserting small pins through the lateral regions of the mesothorax and of the abdomen, or the animal may be fixed in wax by first drying the surface with blotting paper and then immersing its under surface in melted paraffin or wax, and holding it in this position till the wax is cool and solidified.

1. Cut off the elytra and the wings. Carefully cut through the terga of the thorax and abdomen close to each side, and lift these off, avoiding injury to the *heart*, which will now be seen as a straight chambered tube lying in mid-dorsal line

2 Remove the opaque, white mass known as the fat-body, which is filling the space between various organs, and unravel the alimentary canal and its appendages which will be thus exposed. Note the *stomodæum*, consisting of the *buccal cavity*, *œsophagus*, *crop*, and *gizzard*; the *mesenteron* with the *hepatic cæca* connected with its anterior end; and the *proctodæum* consisting of *ileum*, *colon*, and *rectum* (see p 379). Note the two *salivary glands* and a *salivary receptacle* between them, on each side of the anterior portion of the crop, and trace their ducts forwards to where they open in the mouth In doing so take special care that you do not injure the nervous system in the head. Sketch the alimentary canal and its appendages

3. Note the fine thread-like *Malpighian tubules* which are arising as diverticula from the anterior end of the ileum and spreading among the filaments of the fat-body all through the abdomen.

4. Note the respiratory tubes or *tracheæ* commencing at the stigmata (already noticed on the outer surface of the body) ramifying through all parts of the body

5. In the posterior region of the body, look for the reproductive organs. If the specimen is a male, the *testes* and the *vasa efferentia* may not be easily found. The testes are paired and lie embedded in the fat-body immediately below the fourth and the fifth abdominal terga, looking like elongated bunches of a translucent colour in the young specimen, and diminishing in size in the adult. A pair of large tufted *vesiculæ seminales*, together constituting the "mushroom-shaped gland," and the *ejaculatory duct* will easily be found. Note also the chitinous hooks and plates known as the *gonapophyses*, which surround the genital aperture. In the female specimen, note the two *ovaries*, each consisting of a set of eight tubes which show a beaded appearance owing to the contained ova, continued at their

posterior ends into short, wide *oviducts*, which unite and open to the exterior by a median vertical slit in the eighth sternum. Behind these are a pair of unequal cæca of small size, the *spermatheca*, which open by a median aperture on the ninth sternum, and a pair of much-branched *colleterial glands*, whose ducts open independently but close to each other and behind the opening of the spermatheca. Note also the *gonapophyses* situated between the genital aperture and the anus.

Sketch the reproductive organs in the male and in the female specimens, as actually displayed in your dissection.

6. Turn the alimentary canal aside and note the *ventral nerve cord*. Observe that a more marked distinction into ganglia and connectives is seen than in the case of the earthworm, and that the fusion of the two lateral halves of the cord or chain has only affected the ganglia, the connectives being double all the way along. Note the pairs of closely apposed ganglia in the three thoracic and the first six abdominal segments. The last pair are the largest of the abdominal ganglia, and give off nerves to various parts of the sixth and succeeding segments.

For a satisfactory dissection of the parts of the nervous system situated in the head, a second specimen will probably be necessary. Fix the head, with its anterior surface upwards, by means of a fine pin through the upper part of the epicranium and another between the mandibles. Remove the clypeus and the anterior portion of the epicranium with scissors or the point of a scalpel, taking care not to injure the ganglia, which lie close beneath the clypeus. Carefully expose the pair of *supra-œsophageal* or *cerebral ganglia*, from which nerves are given to the eyes and the antennæ, and turning the head on the side and removing the gena and mandible, and as much as is necessary of the first maxilla, submentum, and mentum, expose the *para-œsophageal connectives* and the *sub-œsophageal ganglia*. From the latter nerves are given off to maxillary and labial palps, and connectives run back through the neck to form the anterior part of the ventral nerve-cord. From the para-œsophageal connectives a pair of *visceral nerves* arise, which unite to form a small median ganglion on the anterior wall of the œsophagus just below the cerebral ganglia. From this ganglion a *median recurrent nerve* runs backwards along the dorsal surface of the œsophagus and crop to a small triangular ganglion, from which two branches run obliquely backwards over the surface of the crop. Sketch the nervous system.

C. **Microscopic Preparations.**

1. Remove large trachea, mount in glycerine, and examine its structure. Also remove small portions of muscle from the leg, and of the fat-body, and examine microscopically the fine tubes ramifying through them. Sketch.

2. Tease a small piece of muscle so as to separate its fibres from one another. Stain and mount in glycerine. Note the *transverse striations*, *sarcolemma*, and *nuclei* (compare Fig. 36). Sketch.

3. Tease up a ganglion in salt solution, stain, and examine for nerve-cells. Sketch.

LIFE-HISTORY OF A GNAT.

Collect some water containing mosquito larvæ in a glass jar or a corked specimen tube, only half filling the jar or the tube. Allow the vessel to rest on a table and note the characteristic features and movements of the larvæ, and identify if they are Culicine or Anopheline. Note the changes that take place from day to day, and observe the pupæ and the adult insects, when they emerge.

CHAPTER VII

SURVEY OF THE ANIMAL KINGDOM

We have so far studied examples of the following chief divisions or phyla of the animal kingdom (compare p. 233) :—

Phylum.	*Type.*
Protozoa.	
Class Sarcodina	*Amœba.*
Class Ciliata	*Paramecium, Vorticella.*
Class Sporozoa	Malarial parasites.
Cœlenterata.	
Class Hydrozoa	*Hydra, Obelia.*
Annelida.	
Class Chætopoda	*Pheretima, Nereis.*
Arthropoda.	
Class Crustacea	*Paleamon.*
Class Insecta	*Stylopyga.*
Chordata (including Vertebrata).*	
Class Amphibia	*Rana, Bufo.*

Besides these, there are a number of other important phyla, and our survey of the animal kingdom will be very incomplete without a brief reference to some of them.

* Types of other classes of the Chordata will be described in the succeeding chapters.

Phylum PORIFERA (Sponges).—In sponges, the body consists of many cells lying in close contact with one another, and usually forming a yellowish, asymmetrical mass of varying size, generally attached to a rock or a seaweed and practically motionless like a plant organism. The surface of a sponge is dotted over with minute pores, and one or more larger openings known as *oscula* (Fig. 113, *O.*) also occur. Sponges live always submerged in water, and if a few grains of carmine or some other pigment are dropped in the water near them, it is seen that the grains are drawn *into* the minute "inhalent" pores, and also that they are *driven away* from the larger "oscula." This current of water is produced by the lashing of the protoplasmic threads or flagella possessed by certain of the cells within the body (see Fig. 114, A, *c.*), and it carries into the body both the oxygen necessary for respiration and also the decaying organic matter which probably serves as food.

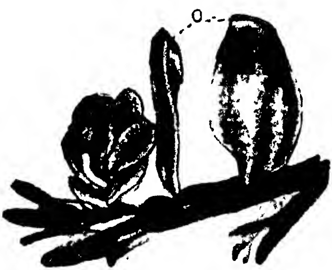


FIG 113.—The Purse Sponge (*Grantia compressa*), natural size, attached to a branch of seaweed. (After Lulham) O. oscula.

The tough texture of the sponges is due to the spicules, which are of a calcareous or siliceous nature, and are embedded in the mesoglœa. They are of very varied shapes in different sponges, and under the microscope are marvels of beauty and symmetry. The spicules may occur alone or combined with a network of horny or silky threads of a substance called *spongin*. In the common Bath Sponges the spongin alone is present, forming the tough supporting skeleton which is sold as a sponge.

These sponges live in deep water, whence they are

obtained by divers, or by means of long-handled pronged forks by which they are speared from boats. The living sponges are covered and penetrated throughout by the slimy living tissues, and it is only after these have decayed and the horny skeleton has been washed free from them that the sponge is ready for household use.

FIG. 114.—A Diagrammatic representation of a longitudinal section through a Sponge of a simple type *c* collared cells, *e* ectoderm, *i* inhalent pores, *o* osculum B one flagellated collared cell, enlarged. (After Lulham)

Phylum **Platyhelminthes** (Flat-worms) consists of small, worm-like creatures, with a soft, flattened, bilaterally symmetrical body, which is either unsegmented or consists of a number of similar segments having very little connection with each other.

The flat-worms are more highly organised than the Cœlenterata and are distinctly triploblastic, but unlike the Annelids they have no body-cavity or cœlom outside the alimentary canal. The mesoderm forms a kind of connective tissue filling up the space between the alimentary canal and the skin, and several important systems of organs, *viz.*, the muscles, the excretory system, and the reproductive ducts, originate from this layer. There is no circulatory system, and the food is carried directly to the tissues through the much-branched digestive tract, which serves, as in the Cœlenterata, as a

Fig 115—The Liver-fluke. *excv* excretory pore; *mo* mouth, *repr.* reproductive aperture, *sckr.* ventral sucker

gastrovascular cavity. There is no anus. The phylum includes the fresh-water planarians, and the parasitic liver-flukes and tape-worms. In the liver-flukes the

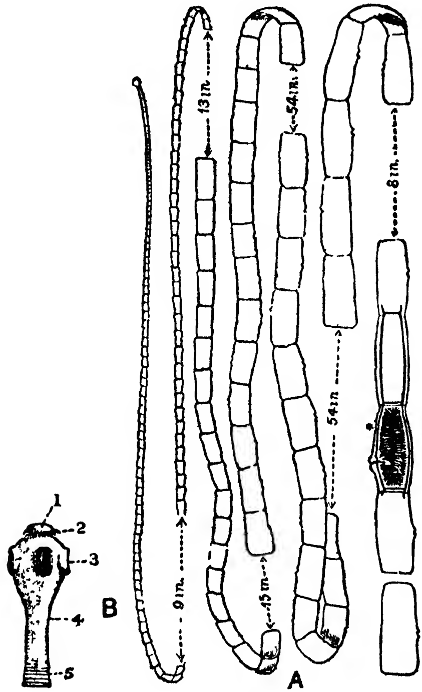


FIG 116 —The Tape-worm.
A. entire animal ; the approximate lengths of the portions omitted in the drawing are given At * the branched uterus and longitudinal and transverse excretory vessels are shown B head or scolex greatly enlarged 1 rostellum, 2 hooks, 3 suckers, 4 neck, 5 commencement of region after which the body is regularly segmented. (A from the *Cambridge Natural History*, B from Shipley and Macbride)

body is provided with suckers (Fig. 115, *sckr.*) by which the parasite clings to the host inside the body of which it lives. The liver-fluke of the sheep (*Distomum hepaticum*) has an extraordinary life-

history, passing the adult phase of its life inside the liver of a sheep, and the earlier stages within the body of a water-snail (*Limnæa truncatula*) or of a land-snail (*Helix*). It passes out from the snail on to the grass, and is then swallowed by the sheep when it eats the grass. The tape-worms (Fig. 116) have a long, ribbon-like, segmented body with no alimentary canal. The segments are very little dependent on each other; each is capable of reproduction, and separates from the rest when ripe, leaving the body of its host and passing the second phase of its life in another host. *Tænia saginata* and *T. solium* are found as parasites in the human alimentary canal, and pass the second phase in their life in the body respectively of an ox or a pig, and then again infects man if the flesh of these animals is eaten without being cooked sufficiently to kill the worms. A tape-worm is very commonly found as a parasite of the pigeon, and can readily be obtained for practical study by slitting open the intestines of a pigeon.

Phylum **Nematoda** (Round worms or Thread-worms).—These are bilaterally symmetrical, triploblastic animals with an elongated cylindrical body, showing no sign of external or internal segmentation. The alimentary canal has a mouth opening at the anterior end and an anal opening on the ventral surface near the posterior end, and lies in a body-cavity or cœlome. Sexes are separate. They are usually small forms, though some of them reach the length of five or six feet. They move with wriggling motion. Most of them are parasites.

Oxyuris vermicularis is the common thread-worm, which is only about half an inch long, and is often found in the human rectum, more particularly in young children. *Ascaris lumbricoides* is the common round worm parasitic in the intestine of man, which may reach a length of a foot or even more. *Trichina spiralis* is

another parasite, at first living in the intestine of man, and then in his muscles, causing a deadly disease known as "trichiniasis." In another phase of its life-history

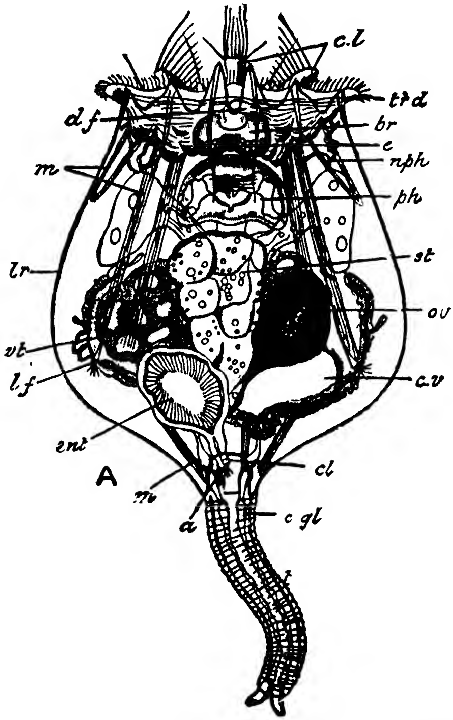


FIG 117—A Rotifer (*Brachionus rubens*) as seen under a microscope. *a* anus, *br* brain, *d f* dorsal feeler, *c gl* cement gland, *cl* cloaca; *c.l.* ciliary lobes, *c v* contractile vesicle, *e* eye-spot, *int* intestine, *lr* lorica, *l f.* lateral feeler, *m* muscular bands, *nph* nephridial tubes, *ov* germarium, *ph* pharynx, *st* stomach, *t.* tail, *tr d* trochal disc, *vt* vitellarium. (After Hudson and Gosse)

it is parasitic in pig, producing what is known as "measly" pork.

Phylum **Rotifera** (Wheel Animalcules).—Rotifers are microscopic but multicellular forms, very commonly

found in the water from ponds and ditches. They are bilaterally symmetrical. The head bears a disc provided with cilia which aid in locomotion and draw food into the mouth. At the opposite end of the body is a tail or foot which is often jointed, and is more or less retractile. The animal is able to fix itself temporarily to any support

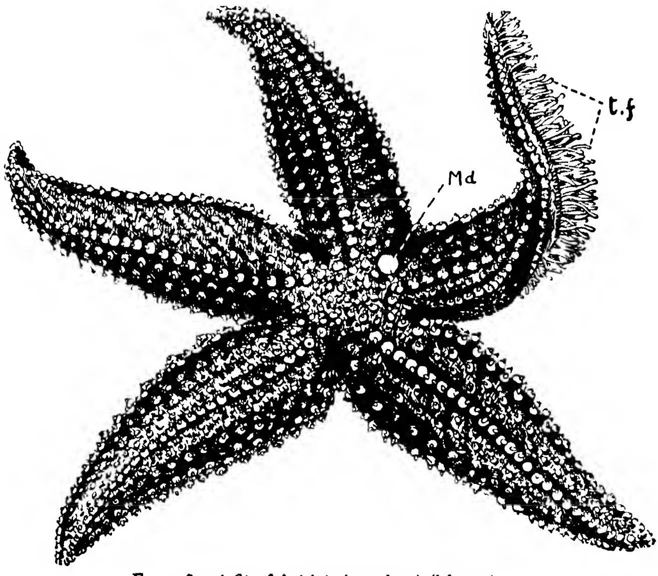


FIG 118.—A Starfish (*Asterias rubens*) (life size)
Dorsal view: one arm is raised to show the tube-feet, *tf* on the ventral surface, *md* madreporite

in water by means of a secretion from a cement gland in the tail. Although of a microscopic size, the animals show a complicated internal structure. They have a body-cavity (cœlome) distinct from the alimentary canal, and also excretory, reproductive, and nervous systems, the brain being relatively large, though the sense organs are very simple. The sexes are separate.

Most of them are inhabitants of fresh water, but some are marine and a few parasitic.

Phylum **Echinodermata** — The Echinoderms are multicellular animals which, like the Cœlenterates, show a radial type of symmetry, but they differ from the latter in possessing a distinct body-cavity or cœlome lying

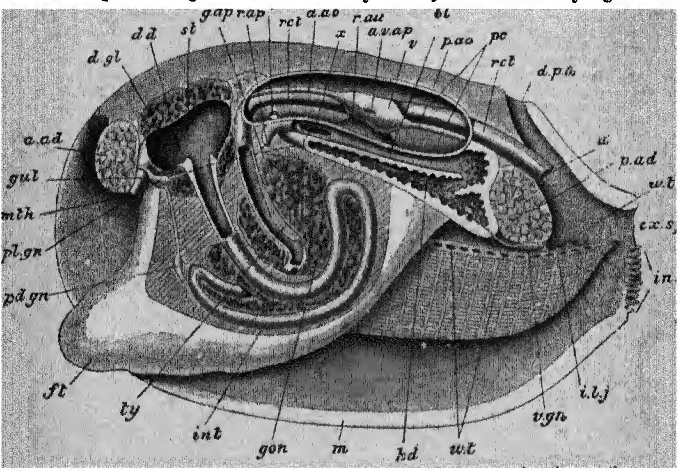


FIG 119 —Dissection of the Fresh-water Mussel, made by removing the mantle-lobe, inner and outer gills, wall of pericardium and auricle of left side *a* anus, *a ad* anterior adductor muscle, *a ao* anterior aorta; *a v ap* auriculo-ventricular aperture, *bl* urinary bladder, *c pl gn* cerebro pleural ganglion, *dd* duct of digestive gland, *d.gl* digestive gland, *d p a* dorsal pallial aperture, *ex sph* exhalent siphon, *ft* foot, *g ap* genital aperture, *gon* gonad, *gul* gullet, *i l j* inter-lamellar junction, *in sph* inhalent syphon, *int* intestine, *kd* kidney, *m* mantle *mth* mouth, *p ao* posterior aorta, *p ad* posterior adductor, *pc* pericardium, *pd gn* pedal ganglion, *r ap* renal aperture; *r au* right auricle, *rct* rectum, *r p a* reno pericardial aperture, *st* stomach, *ty* typhlosole, *v* ventricle, *v gn* visceral ganglion, *w t* water-tubes, *x* aperture between left and right bladder. (From Parker and Haswell's *Zoology*)

outside the alimentary canal and containing various organs in it

They are usually five-rayed forms, and the skin is hardened by small calcareous plates and spines. A special peculiarity of the members of this phylum is the presence of a peculiar water-vascular system, by means

of which water can be taken into the body through an opening known as the madreporite (Fig. 118, *md.*) and pumped into the tube-feet (*tf.*), which in many of them are the chief organs of locomotion. There is no well-defined blood-vascular or excretory system. The sexes are separate. The phylum is large and varied, and includes such forms as starfishes, sea-urchins, sea-cucumbers, all of which are marine

Phylum **Mollusca**.—The phylum Mollusca includes the snails, slugs, mussels, oysters, cuttle-fish, and nautili. They are unsegmented, triploblastic animals,

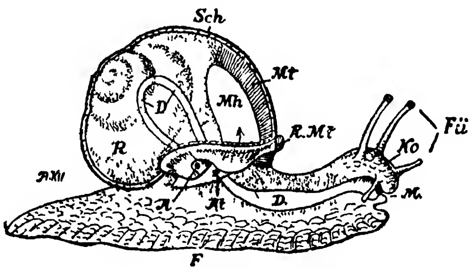


FIG 120 —Diagram showing the structure of a Snail
A. anus, *At* respiratory aperture, the entrance to mantle cavity indicated by arrow; *D* alimentary canal, *F* foot, *Fü* tentacles, *Ko* head, *M* mouth; *Mh* mantle-cavity, *Mt* mantle; *R mt* free edge of mantle, *Sch.* shell (After Schmeil)

primitively bilaterally symmetrical, the bilateral symmetry becoming disturbed in such forms as the snails and the slugs. The bodies of the molluscs are soft and generally covered by a slimy integument. They are thus fitted for life in the water or in moist places. In most of them the body is supported and protected by a shell of calcium carbonate. The shells of snails, cowries, and fresh-water mussels (the latter under the vernacular name of *sipis*) are familiar to everyone. A characteristic organ of the members of this phylum is the ventral muscular *foot* (Fig. 119, *ft.*, Fig. 120, *F.*), which is variously

modified; it enables the mussel to plough its way through the sand, the snail to glide along, and the squid to swim through the water and capture its prey. The mantle (*m.*) is a fold of the body-wall which secretes the shell. If there are two lobes, a bivalve shell is produced, as in the mussel. In a dead and gaping mussel, the general disposition of the parts of the animal is readily seen. The main part of the body lies between the dorsal regions of the valves; it is produced in the middle ventral line into the keel-like foot; and on either side between the foot and the corresponding mantle-lobe are two delicate, striated plates, constituting a *gill* or *ctenidium*. In those forms in which only one mantle-lobe is present a univalve shell is formed, as in the snails (Fig. 120).

The Mollusca possess a distinct *cœlome*, which is, however, confined in the adult to the pericardial cavity and the cavities of the reproductive organs.

PRACTICAL DIRECTIONS

The students should examine a certain number of specimens (or their models) belonging to the various phyla mentioned above, from the college zoological museum.

CHAPTER VIII

SURVEY OF THE ANIMAL KINGDOM (*continued*)

Chordata.—The phylum Chordata (Lat. *Chordatus*, having a chord) includes the vertebrate animals (mammals, birds, reptiles, amphibians, fishes) and certain marine forms that are not generally known except to zoologists. All of them are characterised at some period of their lives by the possession of (1) a skeletal axis, the *notochord* (p. 214), (2) *paired slits* connecting the pharynx with the exterior, and (3) a central *nerve-cord* placed *dorsal to the alimentary canal* and containing a cavity or system of cavities, the neurocœle. In many, some of these features though present during early development are lost by the adult, as the adult frog has lost the notochord and gill-clefts which are present in the tadpole. In many respects the chordates differ widely from one another, and are usually divided into four sub-phyla, viz., Hemichorda, Cephalochorda, Urochorda, and Vertebrata.

Cephalochorda.—In various parts of the world, certain small fish-like animals called lancelets are found, the commonest species of which is known as *Amphioxus lanceolatus* (Fig. 121). This animal, which possesses a median fin like that of the tadpole (p. 218), is not more than a couple of inches in length, and lives in the sea

near the shore, burrowing in the sand; it is especially interesting owing to the fact that it presents certain characteristics indicating a near relationship to the primitive ancestors of Vertebrates. It possesses a notochord, a dorsal hollow nervous system, a pharynx perforated by gill-slits, a hollow out-growth of the intestine representing a simple liver, with a hepatic portal system, and a series of nephridia. But it differs from all the Vertebrates in the following important points.

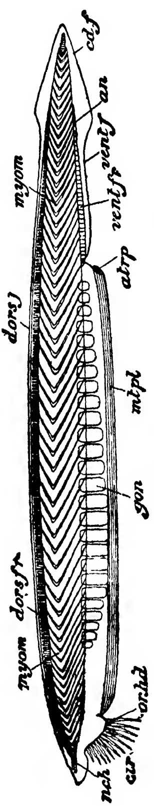


FIG 121—*Amphioxus lanceolatus*, side view (× 2½) *an* anus *atrp* atriopore, *cd f* caudal fin, *cir* cirri, *dors f* dorsal fin, *dors f r* dorsal fin-rays, *gon* gonads *mtpl* metapleure, *myom* myomeres, *nch* notochord, *or hd* oral hood, *vent. f.* ventral fin, *vent f.r* ventral fin-rays (From Parker and Haswell's *Zoology*, after Kirkaldy)

The epidermis consists of a single-layer of cells There is no distinct head and no skull, the persistent notochord (Fig. 122, *nch*) extends to the anterior end of the animal, and there are no paired limbs A brain (*br*) can hardly be said to be present, and there are no paired olfactory, optic, or auditory organs. The pharynx is relatively very large, and is perforated by very numerous oblique gill-slits (*br. cl*) which do not open on the exterior directly, but are surrounded by a chamber, the *atrium* (Fig. 122, *atr*); this opens externally by a pore (Figs. 121 and 122, *atrp*), and though differing in its mode of development from the branchial chamber of the tadpole (p. 215), has somewhat similar relations. There is no heart, and the colourless blood apparently contains no corpuscles

of any kind. The nephridia remain distinct, not being united into a single kidney on either side: they are situated anteriorly, in the neighbourhood of the pharynx (Fig. 122, *nph*), the gonads (Figs. 121 and 122, *gon*) are metamerically arranged, and have no ducts.

These numerous and marked differences between the lancelet and the Vertebrata make it necessary to place it in a separate sub-phylum called Cephalochorda (Gr. *Kephale*, head; *chorde*, cord), the name being given on account of the notochord extending to the anterior end of the body.

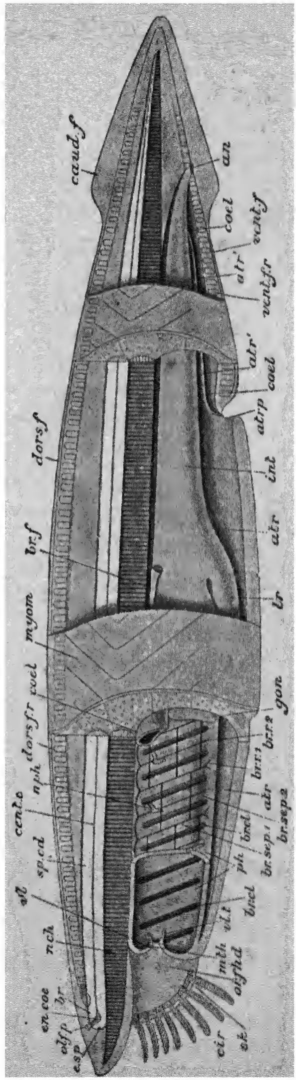


Fig. 122.—Diagram of the anatomy of *Amphioxus*

an anus, *atr* atrium, *atr'* its posterior prolongation *atrp* atriopore, *br* 'brain', *br cl* branchial clefts, *br f* "atrio-cœlomic funnel", *br sep 1*, primary, *br sep 2*, secondary branchial bar, *br r 1*, primary *br r 2*, secondary branchial rod, *caud f* caudal fin *cent. c.* central canal *cir* cirri, *cœl* cœlome, *dors f* dorsal fin, *dors f r* dorsal fin-rays *en coe* cerebral ventricle *e sp* eye-spot, *gon.* gonad, *int* intestine, *lr* "liver", *mth* mouth, *myom* myomeres, *nch* notochord, *nph* nephridia, *olf p* olfactory pit, *or f hd* oral hood, *ph* pharynx, *sk* skeleton of oral hood and cirri (dotted), *sp cd* spinal cord, *vent f* ventral fin, *vent f r* ventral fin-rays, *vl.* velum, *vl t* velar tentacles (From Parker and Haswell's *Zoology*, reduced)

Vertebrata.—From your study of the frog you have learnt something about a vertebrate animal, and in the following chapters we will examine a few more examples of the sub-phylum Vertebrata, which, as we have seen (p. 233), includes several classes, the *Pisces*, *Amphibia*, *Reptilia*, *Aves*, and *Mammalia*. Leaving aside the lampreys and their allies, which present certain peculiarities and are therefore placed in a class by themselves, these all agree with one another and resemble the frog in the following essential characters.

They all possess :—a *vertebral column*—or at any rate a *notochord* which is nearly always replaced by a vertebral column in the adult—and a *skull* with upper and lower *jaws* ; a *dorsal, hollow, nervous system*, consisting of *brain* and *spinal cord*, paired *olfactory organs*, *eyes*, and *auditory organs*, which take on a close connection with the skull ; a *pharynx*, which at an early stage, at any rate, is perforated by a small number (never more than seven) of paired *gill-clefts* (p. 215) ; a *mouth* which is ventral and anterior, and an *anus* which is ventral and posterior ; *kidneys* which are composed of numerous urinary tubules or nephridia ; a chambered *heart* and *red blood-corpuscles* ; a *liver*, and a *hepatic portal system* ; usually *two pairs* of *limbs*, and never more than two pairs ; and a series of *body-muscles* which are divided into segments, or *myomeres* (p. 215), at any rate in early stages, and are composed of striped fibres.

Pisces.—The class *Pisces* (see p. 233) includes a number of aquatic Vertebrates which present a considerable amount of difference in form and structure, and which are distinguished from the Amphibia, as a whole, by certain constant characteristics, of which the following are the chief.

The organs of respiration and locomotion are adapted

for life in the water. The former consist, as in later stages of the tadpole (p. 219), of a series of vascular *internal gills*, attached to the septa separating the gill-clefts, and persist throughout life: only in a very few instances (viz., in the small sub-class constituting the "Mud-fishes" or *Dipnoi*) are lungs and internal nostrils also present. The pectoral and pelvic limbs have the form of paddle-like *fins*, which, like the median fins, are supported by skeletal *fin-rays*:—the median fin is usually subdivided into separate dorsal, ventral, and caudal portions. In addition to the endoskeleton, there is usually an exoskeleton, developed in the dermis and consisting of *scales*; and peculiar *integumentary sense-organs*, occurring also in aquatic and larval Amphibians, and supplied by special nerves not represented in terrestrial Vertebrates, are always present. The cerebellum is relatively large; a tympanic cavity and membrane are not present, and, except in the Dipnoi, there is only *one* auricle in the heart and no postcaval vein. A urinary bladder developed as an outgrowth of the enteric canal (p. 221) is wanting. There is never such a marked metamorphosis as in the case of the frog.

The three sub-classes of the Pisces are the *Elasmobranchii*, *Teleostomi* (including *Ganoidei* and *Teleostei*) and the *Dipnoi*. The Elasmobranchs are all marine forms, and include the Dogfishes, Sharks, Rays, and Skates: their endoskeleton is composed almost entirely of cartilage, like that of the tadpole. The Teleostei, in which the skeleton is mainly or to a large extent bony and a well-developed operculum covers the gills, include by far the greater number of fishes—both marine and fresh-water forms—such as the Cat-fishes, Carps, Herrings. The Dipnoi, or mud-fishes, comprising as their living representatives only three genera, differ from the other fishes in possessing a single or double lung.

For getting a general idea of the anatomy of a fish, any ordinary (bony) fish of the Carp family, *e.g.*, *Labeo rohita* or *L. Calbasu*, may be examined. In most particulars the dogfish, *Scyllium canicula*, is simpler and therefore a very favourite object of study with zoologists.

Carps (*Cyprinidæ*) are well represented in the fresh waters and estuaries of India, Ceylon, and Burma, and along with the cat-fishes (*Siluridæ*) compose the great mass of fish residing there. The body of the common

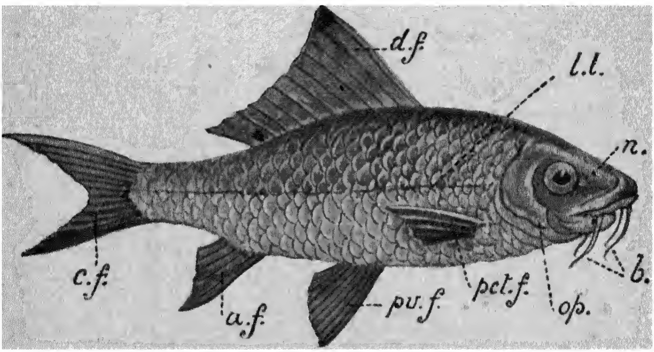


FIG 123 —*Labeo Calbasu*, a common Indian Carp (B L B)
a f anal fin, *b* barbels *c f* caudal fin, *d f* dorsal fin, *l l* lateral line, *n.* nostril, *op* operculum or gill-cover, *pct f* pectoral fin, *pv f* pelvic fin

Labeo Calbasu (Fig. 123) grows to about three feet in length, and is divisible into *head*, *trunk*, and *tail*. There is a single median *dorsal fin* (*d f*), a deeply forked *caudal fin* (*c.f.*), and a single median *anal fin* (*a f.*) just posterior to the anus, two lateral *pectoral fins* (*p.f.*). and two lateral *pelvic fins* (*v.f*) On each side of the body, running from the head to the tail, is a *lateral line* (*l.l.*). The head bears a *mouth* with well-developed jaws, but without teeth, a pair of lateral *eyes*, a pair of *nasal apertures* (*n*) anterior to each eye, and *gill-covers* or *opercula* (*op.*), beneath which are the gills. The snout

is obtuse and depressed, covered with tubercles, and projects beyond the mouth. Two pairs of *barbels* (*b.*) are arising from the snout and the maxillæ Three rows of hooked teeth are present in the pharynx. The head is scaleless, but the skin covering the trunk is provided with rows of *dermal scales* which are arranged in an imbricating manner and protect the fish from mechanical injury. These scales and the fin rays supporting the fins constitute the exoskeleton of the fish.

In the dogfish, note that the large, transversely elongated mouth is on the ventral side of the head, the eyes are protected by thick folds of skin forming upper and lower *eyelids*, five pairs of *gill-clefts* or *external branchial apertures* are situated anterior to the pectoral fins and are not covered by an operculum, and just behind the eye is a small aperture also communicating with the pharynx, which is the functionless first gill-cleft or *spiracle* In the dermis are innumerable close-set, calcified bodies, each consisting of a little irregular bony plate produced into a short spine composed, like the teeth present in the frog and most Vertebrates, of a calcified tissue harder than bone, known as dentine, capped with a still harder tissue called enamel—which project through the epidermis and give a rough, sandpaper-like character to the skin These *placoid scales* or *dermal teeth* together constitute the exoskeleton of the dogfish. Over the jaws they are modified as teeth with their points directed backwards The pelvic fins in the male possess cartilaginous appendages, known as *claspers* The tail is *heterocercal*, *i e*, not symmetrical, and with the vertebral column extending into the dorsal lobe

The body of the carp and of most other fishes is spindle-shaped and offers little resistance to the water through which the animal swims. It is kept at the same weight as the amount of water it displaces by means of an *air-bladder*. The fish is thus able to remain stationary without muscular exertion. The principal locomotor organ is the tail. By alternating contractions of the muscular bands on the sides of the trunk and tail, the tail with its caudal fin is lashed from one side to the other, moving in a curve shaped like the figure 8. During

the flexions and extensions of the tail, the trunk is curved in such a way as to bring about the more effective extension or forward stroke and a weak flexion or non-effective stroke.

The fins are integumentary expansions supported by bony or cartilaginous rays. The paired lateral fins are used as oars in swimming, but only when the fish is moving slowly. They also aid the caudal fin in steering the animal.

Fishes must maintain their equilibrium in some way, since the back is the heaviest part of the body and tends to turn it over. The dorsal, caudal, and anal fins increase the vertical surface of the body, and, like the keel of a boat, assist the animal in maintaining an upright position. The paired lateral fins are also organs of equilibration, acting as balancers.

The skeleton of a bony fish (Fig. 124) consists principally of bones, and includes the skull, vertebral column, ribs, pectoral girdle, and the rod-like bones which support the fins. The bones of the fish are not as strong as those of the land animals, as the body is to a considerable extent supported by the surrounding water.

The skull of the carp (Fig. 124) consists of a large number of replacing and investing bones, the cartilage of the original chondrocranium persisting in a few places only. The parts of the skull may be grouped into the cranium and the visceral skeleton. The *cranium* protects and supports the brain, auditory organs, and olfactory sacs, and furnishes orbits for the eyes. Of the large number of bones of which it is composed, it is easy to make out a *supra-occipital* (*s.o.*), two *ex-occipitals* (*ex. oc.*), some of the *bones of the auditory capsule* (*ep. o.*, *pr. o.*, *pt. o.*, *sph. o.*) two *parietals* (*p.*), two *frontals* (*f.*), a *mesethmoid* (*me.*), and a pair of *ect-ethmoids* (*le*), from above, and a *basi-occipital*, a *para-*

sphenoid, and a *vomer* from below. The visceral skeleton is composed of seven arches more or less modified. The first or *mandibular* arch forms the jaws. The *upper jaw* consists principally of two pairs of bones, the *premaxillæ* (*pmx*) and the *maxillæ* (*mx*), the latter do not enter into the border of the mouth and neither of them bears any teeth. The *lower jaw*, or *mandible*, is also without teeth, and consists of two rami which do not unite in the middle. The second or *hyoid arch* consists of two paired halves which unite in the middle and give support to a number of curved rods of bone. Arches three to seven support the gills and are known as the

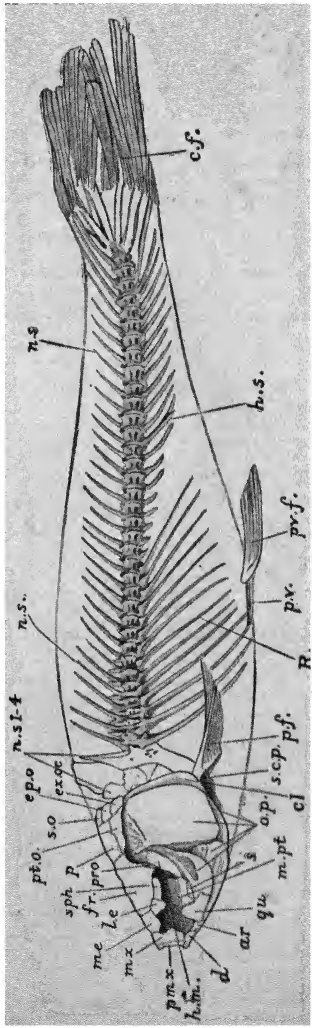


FIG 124.—Skeleton of *Labeo rohita* (B L B)

ar articular, *c.f* caudal fin, *cl* clavicle, *d* dentary, *ep o* epiotic, *ex oc* ex-occipital, *fr* frontal, *h m* hyomandibular, *h s* hæmal spine, *l.e* lateral ethmoid, *me* mesethmoid, *m pt* mesopterygoid, *mx* maxilla, *n s* neural spine, *n.s* 1—4, neural spines of first four vertebræ, *op* bones of the operculum, *p.* parietal, *pf* pectoral fin, *pmx* premaxilla, *pro* pro-otic, *pt.o.* pterotic, *pv.* basi-pterygium, *pv f* pelvic fin, *qu* quadrate *R* rib *s* symplectic, *s c p.* scapulo-coracoid portion, *s o* supra-occipital *sph* sphenotic

branchial arches, the ventral portions of some of them being fused to form an *inferior pharyngeal bone.* The first four branchial arches bear spine-like ossifications, the gill-rakers, which act as a sieve to intercept solid particles and keep them away from the gills. The *operculum* (*op*) on each side consists of four distinct bones.

The skull of the dogfish is very instructive. The cranium or brain-case (Fig 125, *cr*) is an irregular cartilaginous box containing a spacious cavity for the brain, very similar to the chondrocranium of the frog (p 45). It is produced into two pairs of outstanding projections, a posterior pair, called the *auditory capsules* (*aud cp*), for the lodgment of the organs of hearing, and, in front of the brain-cavity, an anterior pair, the *olfactory capsules* (*olf cp*) for the organs of smell. On either side the cranium is hollowed into an *orbit* (*or.*) for the reception of the eye On the roof of the skull, between and behind the olfactory capsules, there is a *fontanelle* (p 45) closed over by connective-tissue only Both the upper and the lower jaw (*up j*, *l j*) are connected with the cranium by ligaments (*lg lg'*) only, and each consists of strong, paired (right and left) halves united anteriorly with one another by fibrous tissue The upper jaw corresponds to the *palatoquadrate* cartilage of the frog (p. 45) and articulates with the lower jaw or *mandibular* cartilage, allowing an up and down movement in the vertical plane. The remaining six pairs of visceral arches have on either side the form of cartilaginous half-hoops, lying in the walls of the pharynx, and united with one another below, so as to form a basket-like apparatus supporting the gills The second or *hyoid arch* is situated immediately behind the jaws The remaining five arches (*br a* 1—*br. a.* 5) are called the *branchial arches.*

In the frog-tadpole the gills are similarly supported by cartilaginous arches, which become greatly reduced and modified at metamorphosis: the hyoid cartilage of the adult (p. 40) represents the hyoid and first branchial arch.

The vertebral column has the general character of a jointed tube, supporting and surrounding the spinal cord.

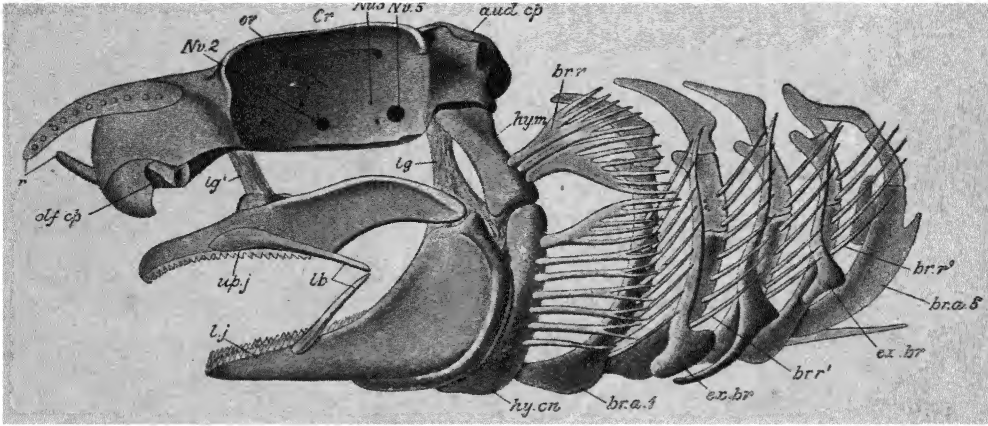


Fig 125 —Side view of skull of *Scyllium canicula* (Nat size)

The cranium (*Cr*) shows the projecting auditory capsule (*aud cp*), the hollow orbit (*or*), the olfactory capsule (*olf cp*), and the cartilages of the rostrum or beak (*r*) In the orbit are seen apertures for the optic (*Nv* 2), oculomotor (*Nv* 3), and main divisions of the facial and trigeminal (*Nv* 5) nerves the ophthalmic divisions of nerves 5 and 7 pass out dorsally to the two last-mentioned apertures and extend along the groove shown in the dorsal wall of the orbit Articulated with the auditory capsule is the dorsal part of the hyoid (*hy m*) helping to support the upper (*up j*) and lower (*l j*) jaws Following upon the hyoid come the five branchial arches (*br a* 1–5) (From Parker's *Biology*, after W K. Parker)

In the embryo dogfish, as in the tadpole, before the development of the vertebral column, an unsegmented, cellular rod with an elastic sheath, the *notochord*, resembling that of Amphioxus (p 412), lies beneath the neural cavity in the position occupied in the adult by the line of centra, by the development of which it is largely replaced

The skeleton of the median fins consists of a series of parallel rods, the *fin-rays*.

The appendicular skeleton is represented in the carp by a *pectoral girdle* only. The pectoral fins (Fig. 124, *p.f.*) are supported proximally by four rod-like bones, and distally by dermal fin-rays. There is no pelvic girdle. The pelvic fins articulate with a flat bone.

The mouth is without any teeth. The pharynx communicates with the outside by four gill-slits on either side. A short, wide œsophagus leads to an elongated stomach, which is followed by a long intestine thrown into several loops The carp breathes by means of four pairs of gills. Each gill bears a double row of filaments, which are abundantly supplied with blood-vessels: Afferent branchial vessels carry the blood from the heart to the gill-filaments (Fig. 126, *a.br.a*), where gaseous exchange takes place, carbon-dioxide being passed out of the blood and oxygen taken in from the water which bathes the gill-filaments. The oxygenated blood is collected by the efferent blood-vessels, which unite to form the dorsal aorta supplying branches to all parts of the body. The oxygenated blood thus goes directly to the body without being first collected in the heart. The heart thus consists of a series of chambers, a sinus venosus, a single auricle and a single ventricle, all of which contain venous blood only.

The arrangement of the arteries in the tadpole is very similar to that in a fish, and the diagram (Fig. 126) would serve almost equally well for a tadpole as for a fish. In

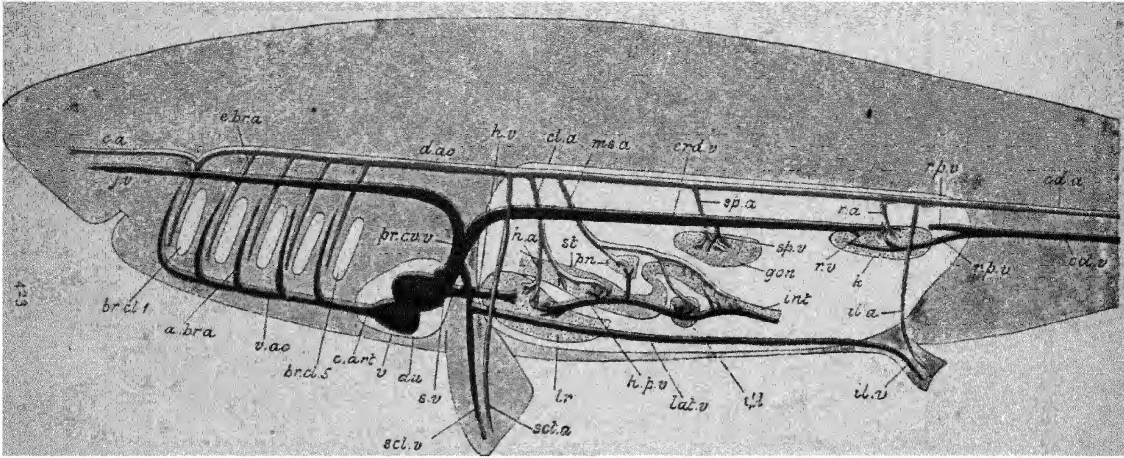


FIG 126 —Semidiagrammatic side view of the vascular system of a Dogfish Vessels containing aërated blood red, those containing non-aerated blood blue (× ½)

a br a afferent branchial artery, *au* auricle, *br cl 1–5*, branchial clefts, *c a* carotid artery, *c art* conus arteriosus; *cd a* caudal artery, *cd v* caudal vein, *cl a* cœliac artery, *crd v* cardinal vein, *d ao* dorsal aorta, *e br a* efferent branchial artery, *gon* gonad, *h a* hepatic artery, *h p. v* hepatic portal vein, *h v* hepatic vein, *il a* iliac artery, *il v* iliac vein, *int* intestine, *j v* jugular vein, *k* kidney, *lr.* liver, *lat v* lateral vein, *ms a* mesenteric artery, *pn* pancreas, *pr. cv v* precaval vein; *r a* renal artery, *r p v* renal portal vein, *r v* renal vein, *scl a* subclavian artery, *scl v* subclavian vein, *sp a* spermatic artery, *spl* spleen, *sp* spermatic vein; *st* stomach, *s. v* sinus venosus; *v* ventricle, *v ao* ventral aorta. (From Parker and Haswell's *Zoology*)

the tadpole there are four pairs of afferent branchial arteries in relation with the corresponding arches and their gills. The afferent and efferent vessels at first communicate with one another through the capillaries in the gills, but later on each afferent becomes directly connected with the corresponding efferent artery; and at metamorphosis, when the gills gradually disappear, all the blood passes directly into the four arterial arches. The first arch gives rise in the adult frog to the carotid trunk, the second forms the systemic trunk, the third disappears, and the fourth, losing its connection with the dorsal aorta, forms the pulmo-cutaneous trunk.

The nervous system is constructed on a similar plan to that of the frog and of vertebrates in general.

The following is an abridged* classification of the Pisces.

A. **Cartilaginous Fishes.**—Pisces in which the skeleton is formed of cartilage, strengthened by calcareous matter, but true bone is not developed. There is no air-bladder. There is a single nostril on each side. The eggs are few and large, a large part or the whole of development being completed before laying.

Order Elasmobranchi.—Cartilaginous Fishes in which there is no operculum; the skin is covered with placoid scales; the upper jaw, though it may articulate directly with the skull, is not fused with it; the notochordal sheath is segmented into distinct centra. (*Scyllium.*)

B. **Bony Fishes.**—Pisces in which true bone is present. An air-bladder is developed as an outgrowth of the alimentary canal. A gill-cover, or operculum, is developed from the hyoid. Each nostril is divided into two openings. The eggs are small, and the young emerge from them as larvæ which undergo a long period of development before becoming adult.

* Groups like Holocephali and Ganoidei are omitted.

larvæ which undergo a long period of development before becoming adult.

Order Teleostei.—Bony Fishes in which bony amphicœlous vertebræ are developed, remains of the notochord persisting between the centra. In the skull are developed a number of investing and replacing bones. The upper jaw articulates with the skull in front and is supported by the hyoid behind. The tail is homocercal. The conus arteriosus is absorbed into the ventricle, and only one transverse row of pocket valves persists. There is no spiral valve in the intestine. The testis has a special duct opening by a special pore, and in both sexes excretory and genital ducts open to the exterior separately from the alimentary canal. In the brain the optic nerves never form a chiasma, but usually simply cross each other. (*Labeo.*)

Order Dipnoi.—Bony Fishes in which the vertebral column is not divided into vertebræ, the notochord being surrounded by an unsegmented cartilaginous sheath. Few cartilage bones are developed in the skull, but there are a number of roofing membrane bones. The upper jaw is fused with the cranium. Body is covered with thin cycloid scales. Tail is diphycercal. Paired fins are typically long and biseriate. There is a spiral valve in the intestine. There are gills attached to the branchial arches, and, in addition, the air-bladder opens into the ventral wall of the pharynx and functions as a lung. There is a distinct conus in the heart, containing a spiral longitudinal valve; there are two auricles, a posterior vena cava is present, and pulmonary veins return blood from the lung to the heart. Oviduct has a funnel-like opening in the cœlome. There is an optic chiasma in the brain.

Reptilia.—We must next refer to another class of vertebrates, the Reptilia, with which the birds show a certain degree of resemblance in their structural organisation, and from which indeed they are believed to have been evolved in the past The reptiles that are living to-day are but a remnant of the vast hordes that inhabited the earth's surface in earlier geological eras. Among its living representatives the class includes the Lizards, the Snakes, the Turtles and Tortoises, and the Alligators and Crocodiles. They show a superficial resemblance with the Amphibia, but there are many points of structure which mark them off as a distinctly higher class. One important feature of the Reptilia which marks them off sharply from the Amphibia is that *lungs* are the sole organs of respiration, gills being never developed at any stage. Another is the development in the embryo of two structures known as the amnion and the allantois (see p 592), which are not present in the Fishes and the Amphibia In both these respects the reptiles resemble the Birds and the Mammals. Further,

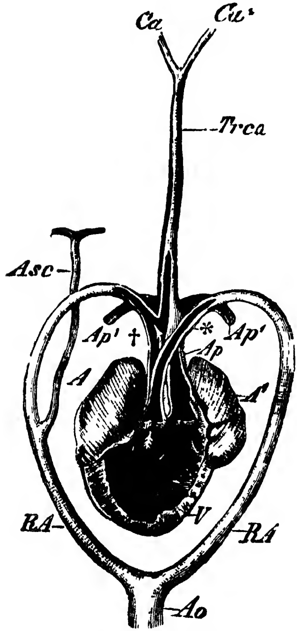


FIG 127—Heart of a large Indian Lizard (*Varanus*) dissected to show the cavity of the ventricle and the vessels leading out from it

A A' auricles, *Ao* dorsal aorta, *Ap Ap'* pulmonary arteries, *Asc* subclavian artery, *Ca Ca''* carotids, *Ra, Ra'* roots of dorsal aorta, *Trca* innominate trunk, *V* ventricle, † right aortic arch, * left aortic arch (From Wiedersheim)

as in Birds, the *eggs* as they are laid are large and provided with plenty of yolk.

The most striking external difference between an Amphibian and a Reptile, on the one hand, and a Reptile and a Bird, on the other, is the possession by the Reptiles of a covering of horny epidermal *scales*, and frequently also (as in turtles and crocodiles) an armour of dermal bony plates. Both pairs of *limbs* (except when absent, as in the snakes) are adapted for raising the weight of the body in progression on land or in water. *Teeth* are present in the jaws, except in turtles and tortoises, where the jaws have a horny investment. In the *heart* (Fig. 127) the sinus venosus is always distinct, and, as in Amphibia, there are always two distinct auricles (*A*, *A'*), the right receiving the venous blood from the body, the left the oxygenated blood brought from the lungs by the pulmonary veins. But a vital point of difference between the heart of the reptile and that of the amphibian is that in the former the ventricle is always more or less completely divided into right and left portions. In the lizards, snakes, and tortoises, the ventricle is incompletely divided by a septum which does not entirely cut off the two portions from one another. But in the crocodiles the cavity is completely divided, so that we may speak of distinct right and left ventricles There are two *aortic arches* present.

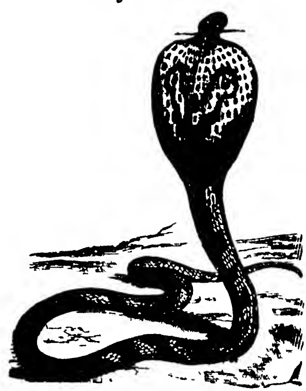


FIG 128 —The cobra, *Naja tripudians*. (From Gadow)

The following is an abridged classification of the living Reptilia.

Order Squamata.—Reptilia with horny epidermal scales.

Sub-order Lacertilia.—Squamata with limbs usually present and adapted for walking. The two halves of the mandible are firmly united at the symphysis, and the mouth is capable of being opened to a moderate extent. Lizards.

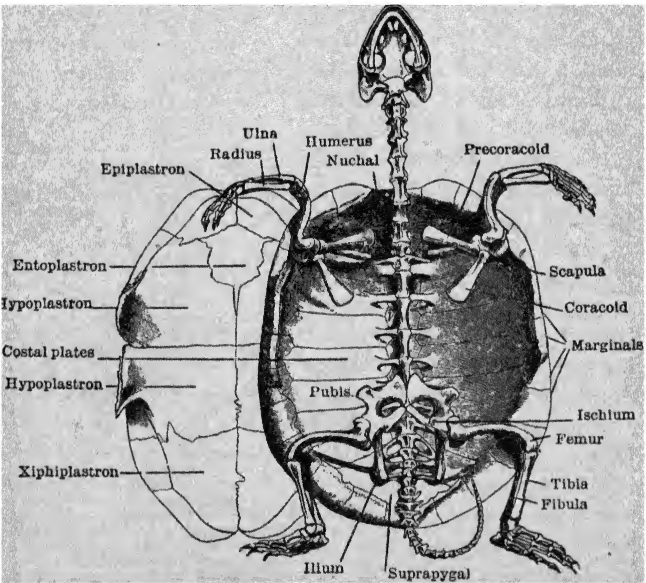


FIG 129 —Skeleton of a turtle, *Cistudo lutaria*, ventral aspect, plastron removed to one side (From Zittel)

Sub-order Ophidia—Squamata with limbs absent, and the body adapted for a creeping mode of life. The two halves of the mandible are connected by elastic fibres, so that they are capable of being widely separated during swallowing. Snakes.

Order Chelonia.—Reptilia with the body enclosed in a shell of bony plates, partly of dermal and partly of ordin-

ary endoskeletal elements. Epidermal horny plates are also present. Limbs with clawed digits adapted for life on land, or sometimes modified into flippers. Teeth are absent, and the jaws have a horny covering. Tortoises and turtles.

Order Crocodilia.—Reptilia with dermal bony plates covered over by horny epidermal scales. Limbs are adapted for walking. Jaws are exceedingly long and provided with teeth implanted in sockets. The ventricle

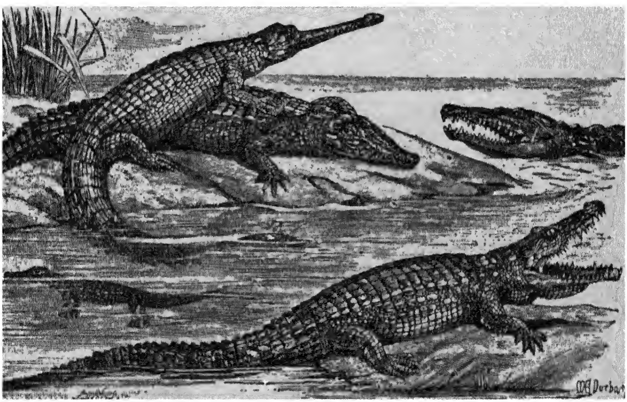


FIG 130 —Crocodiles A long-snouted gharial (*Gavialis gangeticus*) shown on top of an American crocodile (*Crocodilus americanus*) A Nile crocodile (*Crocodilus niloticus*) in the foreground A "mugger" (*Crocodilus palustris*) in the right upper corner Notice peculiar floating attitude of young (From Gadow)

of the heart is completely divided Crocodiles, Gharials and Alligators.

Aves.—The class **Aves** contains the Birds. Birds are easily recognised from all other animals, since they alone possess *feathers*. As a class they are adapted for aerial life, and almost every part of their organisation is modified in accordance with this unusual environment The non-conducting covering of feathers; the modifications of fore-limbs as wings, of the sternum and

shoulder-girdle to serve as origins of the wing-muscles, and of the pelvic girdle and hind-limbs to enable them to support the entire weight of the body on land; the perfection of the respiratory system, producing a higher temperature than in any other animal; all these peculiarities are of the nature of adaptations to flight. The Birds form a homogeneous group, and the structural differences on which the various orders and families are based are comparatively slight. It is usual to select the pigeon as a type for laboratory study. The Common or Domestic Pigeon is known under many varieties which differ from one another in size, proportions, coloration, details, in the arrangement of the feathers, and in many points of internal anatomy. All of them — carriers, tumblers, fantails, pouters, etc. (Fig. 208, p. 632)—have been derived from the blue rock pigeon, *Columba livia* (Fig. 131).

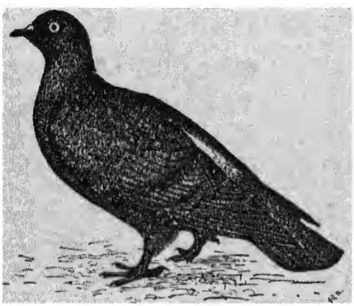


FIG 131 The blue Rock Pigeon *Columba livia* (From Brehm.)

The body of the pigeon is boat-shaped, and therefore adapted for movement through the air. It consists of three regions—head, neck, and trunk. The *head* is prolonged in front into a pointed, horny *beak*, at the base of which is a patch of naked, swollen skin, the *cere*. Between the beak and the cere are the two oblique slit-like *nostrils* (Fig. 131). On either side is an *eye* which is provided with upper and lower lids, and with a well-developed third eyelid or *nictitating membrane*, which can be drawn across the eyeball from the inner angle outward. Below and behind each eye is an

external *auditory aperture* which leads to the tympanic membrane. The *neck* is long and flexible At the posterior end of the trunk is a projection which bears the tail-feathers radiating in a fan-like manner. The two *wings* can be folded close to the body or extended as in flight. When the wing is stretched out at right angles to the trunk twenty-three large feathers (Fig. 132) are seen to spring from its hinder or postaxial border: these are

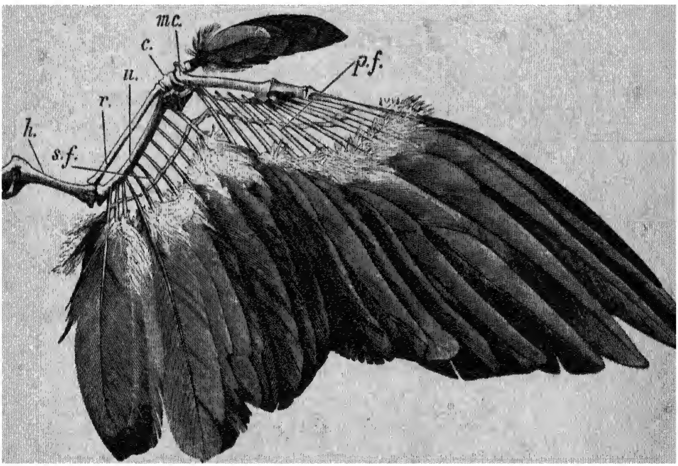


FIG 132 —The wing of a Dove
c. carpals, *h* humerus, *mc* carpo-metacarpus, *p f* primary quills *r* radius; *s f* secondary quills, *u* ulna (After Thomson)

the wing-quills. Twelve of them are connected with the ulna and are called secondaries. The remaining eleven arise from the metacarpal of the second digit, and from the phalanges of the second and third digits, and are known as primaries. A tuft of feathers borne by the first digit is known as bastard wing. In the *hind-limb* the short thigh is closely bound to the trunk; the foot is clearly divisible into a proximal portion, the tarso-metatarsus (Fig 134, *t.m.*), and four digits, of which the

first, or hallux, is directed backwards, and the remaining three forwards. The tarso-metatarsus and digits of the foot are covered with horny epidermal *scales*, and each of the digits of the foot is terminated with a horny *claw*. The *cloacal aperture* is a large, transversely elongated aperture situated on the ventral side of the base of the tail.

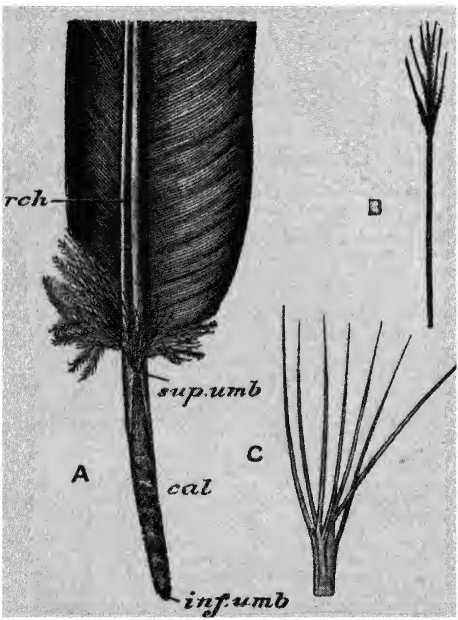


FIG 133 —Feathers of the Pigeon
A portion of a quill feather, *cal* calamus, *inf umb* inferior umbilicus, ***rch.*** rachis, *sup umb* superior umbilicus. B. filoplume C nestling down (From Parker and Haswell)

Feathers arise, as do the scales of reptiles, from dermal papillæ with a covering of epidermis, and become enveloped in a pit, the feather follicle. A typical feather (Fig. 133, A), consists of a stiff axial rod, the proximal portion of which is hollow and semi-

transparent, and is called the *calamus* or quill (*cal.*), the distal portion of the feather is called the *vane*, and part of the stem passing through it the *rachis* (*rch*). The vane is composed of a series of parallel *barbs*, and each barb bears a fringe of small processes, the *barbules*, along either side, by which the adjacent barbs are hooked together. The whole structure is thus a flexible but nevertheless resistant organ, wonderfully adapted for use in flight.

The feathers are of several kinds: (1) the *quills*, like that just described; (2) the *contour feathers*, similar but smaller, cover the general surface of the body, those covering the bases of the quills being known as *coverts*; (3) the *down feathers* possess a soft shaft and a vane in which there is no interlocking of the barbs, they lie beneath the contour feathers Nestling pigeons are covered with down feathers in which the barbs arise directly from the end of the quill (Fig. 133, C), and when they first appear each is covered by a horny sheath like a glove-finger. (4) The *filoplumes* (B) possess a slender hair-like shaft and a few barbs, and are found among the contour feathers.

Only certain portions of the pigeon's body bear feathers; these feather-tracts are termed *pterylæ*, and featherless spaces are known as *apteria*. Occasionally the birds shed their old feathers, *i.e.*, *moult*, and replace them with a new set formed within the follicles and from the papillæ of those that are cast off.

The principal differences between the skeleton of a bird and that of a reptile are those due to the peculiar methods of locomotion of the former. The hind-limbs and pelvic girdle are modified for *bipedal locomotion*; the forelimbs and pectoral girdles are modified for *flight*; the skeleton of the trunk is rigid; the *sternum* has a distinct crest for the attachment of the large

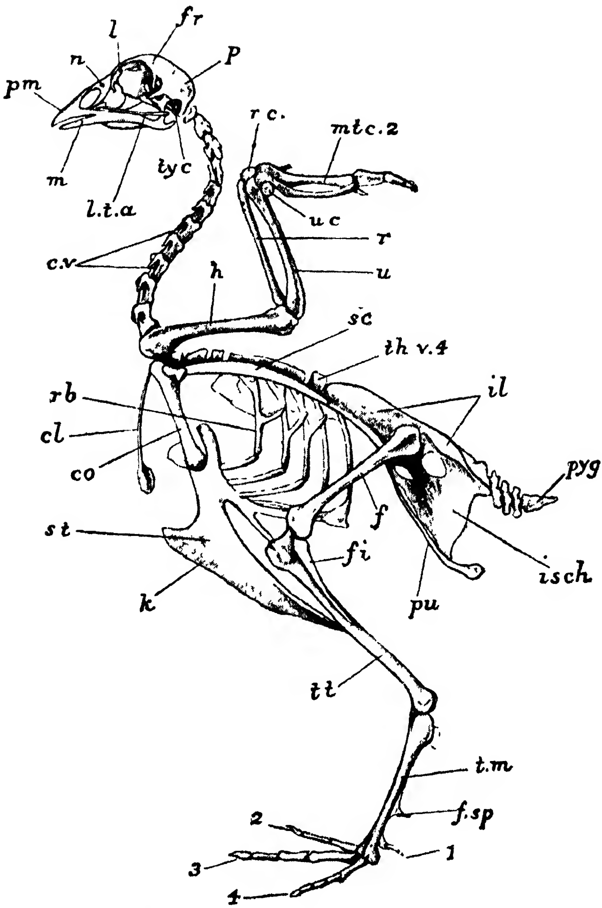


FIG 134 —The skeleton of the common Fowl seen from the left side (B L B) *cl.* clavicle, *co.* coracoid, *c v.* cervical vertebræ, *f* femur, *fi* fibula, *fr.* frontal, *f. sp.* fighting spur, *h* humerus, *il* ilium, *isch* ischium, *k* keel of the sternum, *l* lacrymal, *l. t. a* lower temporal arcade, *m* mandible, *mtc* 2 middle metacarpal, *n* nasal, *p.* parietal, *pm* premaxilla; *pu* pubis, *pyg* pygostyle, *r* radius, *rb* rib, *r. c.* radiale, *sc* scapula, *st* sternum, *u.* ulna, *u c* ulnare, *th v* 4, fourth thoracic vertebra, *t m* tarso-metatarsus, *tt.* tibio-tarsus, *ty c.* tympanic cavity, 1, 2, 3, 4, toes.

muscles which move the wings; some of the ribs have short *uncinate processes* extending backwards from them which make the thoracic framework more firm; and the bones are very light, many of them containing *air-cavities*. The skeleton of the common fowl (Fig 134) is larger than that of the pigeon and easier to study from.

The *skull* is very light, and most of the bones in it are so fused together that they can be distinguished only in the young bird. The *cranium* is rounded, and its base is strengthened by a large membrane-bone, the *basi temporal*, the *orbits* are large and placed almost entirely in front of the cranium and separated from each other by a thin inter-orbital septum, the facial bones extend forwards into *beak;* the *quadrate* is movable and connects the lower jaw with the squamosal; there is a *single occipital condyle* for articulation with the first vertebra, and *no teeth* are present.

A rounded cranial portion behind may be distinguished from a tapering facial portion in front, the two being loosely connected together and capable of slight movement upon each other.

The powerful downstroke of the wing by which the bird rises into and propels itself through the air is performed by the *pectoralis major*, an immense muscle having about one-fifth the total weight of the body; it arises from the sternum and its keel, and forms what is popularly known as the "breast" of the bird. Its fibres converge to their insertion into the ventral aspect of the humerus, which it depresses. The elevation of the wing is performed by the *pectoralis minor*, a smaller and more deeply placed muscle, covered by the first, which sends its tendon through a foramen to be inserted into the dorsal aspect of the humerus.

Connected with the leg muscles is an arrangement

which enables the bird to maintain itself upon a perch even when asleep. If the hind-limb is bent, a pull is exerted on a tendon which flexes all the toes and bends them automatically round the perch Thus when the bird is resting the mere weight of the body bends the hind-limb and consequently causes the toes to grasp the perch and hold the bird firmly in place

The gullet is usually enlarged into a *crop* (Fig. 135, 3); the food, consisting of grain, undergoes a process of softening before being passed into the stomach The stomach consists of two parts, the *proventriculus* with thick glandular walls which secrete the gastric juice, and a thick muscular *gizzard* (14) which has a horny epithelial lining and grinds up the food The junction between the small intestine and large intestine is marked by a pair of cœca. The last portion of the alimentary canal is the *cloaca*, into which the urinary and genital ducts also open.

The lungs (Fig. 135, 12) are solid, spongy organs which are slightly distensible The bronchi also give off branches which on reaching the surface of the lungs bulge out into large air-sacs. The voice is produced in a *syrinx*, situated at the junction of the trachea with the bronchi. The heart is of great proportional size, and, like that of the Crocodile, consists of four chambers, right and left auricles (11) and right and left ventricles (10). There is no sinus venosus, that chamber being, as it were, absorbed into the right auricle. The right auriculo-ventricular valve is a large muscular fold, and the left consists of two membranous flaps The venous blood is received by the right auricle and pumped by the right ventricle to the lungs The oxygenated blood is returned to the left auricle, passes into the left ventricle, and is pumped into the aorta, which curves over to the right side, and supplies branches to all parts of the body. The red

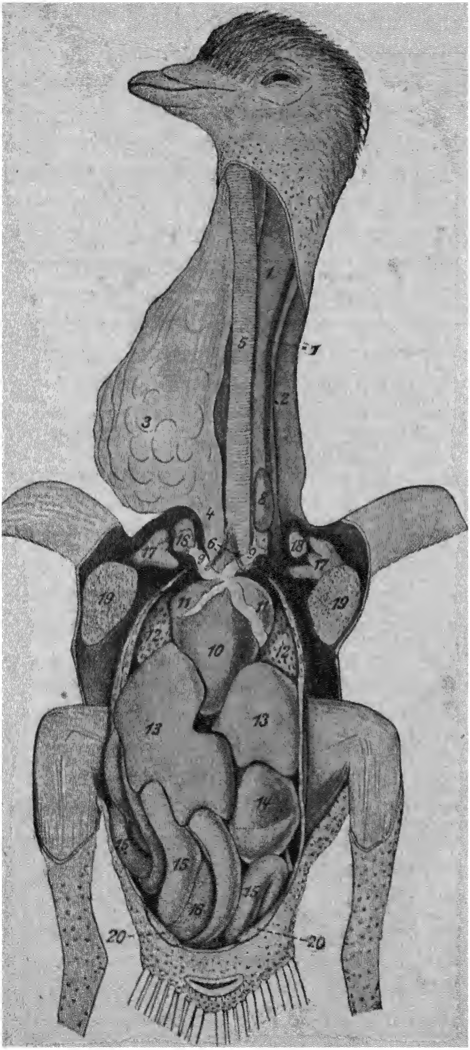


Fig 135.—Dissection of Pigeon from the ventral side, showing the organs *in situ*.

1. Cervical vertebræ covered with muscles; 2 skin of the neck, 3 crop, 4 gullet, 5. trachea, 6. sterno tracheal muscles, 7 left jugular vein, 8 left thyroid, 9 arterial trunks, 10. ventricles, 11. auricles, 12 lungs, 13. liver, 14. gizzard, 15 coils of the intestine, 16. pancreas, 17. humerus, 18. scapula, 19. pectoralis major (cut through), 20. pubes (After Roseler and Lamprecht.)

blood-corpuscles are oval and nucleated. The blood has a temperature of over 100° F., which is higher than that of mammals.

The kidneys are three-lobed. There is no urinary bladder, the ureters opening directly into the cloaca. In the female bird the right ovary and oviduct are atrophied. Birds are oviparous, the large ovum, containing plenty of food-yolk, becomes covered with albumen, shell-membrane and shell, during its descent through the oviduct. Fertilisation is internal and takes place before the ovum becomes invested by the albumen and the other coats. In fact, during the latter part of the descent of the egg down the oviduct, segmentation of the ovum has already started. After the eggs are laid, the process of development of the embryo is resumed by the parent sitting on them and keeping them at a temperature of about 104° F. At the end of the period of incubation the young bird is sufficiently developed to break the shell and begin free life.

In the brain the cerebral hemispheres are very large and the cerebellum also of great size. The hemispheres meet the cerebellum, and the optic lobes are thus displaced to a lateral position. The intelligence, the sense of hearing and the sense of sight are all highly developed, but the sense of smell is very poor.

All the present-day living Birds may be conveniently grouped into two main divisions—the **Ratitæ** and the **Carinatæ**—the former comprising only the Emus (*Dromæus*) Cassowaries (*Casuarius*), and Kiwis (*Apteryx*), the South American Ostriches (*Rhea*), and the true Ostriches (*Struthio*); and the latter including all the rest.

Ratitæ.—Flightless, usually of large size, having no hooked barbules to the feathers, so that the barbs are

free. The tail-feathers are absent or irregularly arranged and the pygostyle is small or undeveloped. The sternum is devoid of a keel. The coracoid and scapula are comparatively small and completely ankylosed, and the angle between them approaches two right angles The wings are reduced in size and may be vestigial or absent.

Carinatæ.—The sternum is keeled except in some flightless forms. The coracoid and scapula meet at nearly a right angle. There is a pygostyle around which the tail-feathers are arranged. The barbules of the feathers are hooked together.

PRACTICAL DIRECTIONS

I Examine an entire specimen of Amphioxus and note the general form of the body, the continuous median fins and the paired lateral fins In a small specimen mounted on a slide and examined under a microscope note the *notochord*, extending from the enterior end to the posterior end of the body, the *neural canal* enclosing the spinal cord, lying just above the notochord, and the arrangement of the *gill-slits* in pairs.

II. For obtaining a general idea of the anatomy of a fish, any bony fish commonly found in the locality may be examined. Note the division of the body into *head, trunk* and *tail*, the median *dorsal, caudal* and *anal fins*; the paired *pectoral* and *pelvic fins*; the *dermal scales* arranged in an imbricating manner over the trunk, the *gill cleft*, and the *anal* and *urinogenital openings*. In connection with the head note the *mouth* (with well-developed jaws, but with no teeth), *eyes*, paired *nasal apertures, opercula, barbels*, and on opening the mouth rows of teeth far back on the floor of the pharynx. Sketch from the side Compare the external characters with those of the dogfish, and note the peculiar features of the latter.

III. Examine a skeleton of the dogfish, noting the relations of the parts in the entire skeleton (viz, cranial and visceral portions of the skull, trunk and caudal vertebræ, and the skeleton of the median and the paired fins). In connection with the skull (Fig. 125) note the *cranium*, showing the fontanelle dorsally, and the nerve foramina in the orbit, the *auditory* and the *olfactory capsules*; the

upper and the *lower jaws;* and the *hyoid* and the five *branchial arches.* Examine also the skeleton of the bony fish to obtain a general idea of the various parts (Fig 124).

IV. Examine a pigeon or any other bird and note the division of the body into head, neck, trunk and limbs, the relatively great length of the neck, and the absence of a true tail. Note mouth, toothless beak, cere, external nares, eyes with upper and lower eyelids, and a nictitating membrane, the auditory aperture and the cloacal aperture

Observe the general covering of the feathers, and pluck the feathers, observing the general arrangement of feather tracts and featherless areas. Note the different kinds of feathers and their structure. From one wing remove all the coverts, and note the number and arrangement of the quills on different parts of the fore-arm. Note the alar membranes and the bastard wing. Note also the quills forming the "tail."

V. Examine an articulated skeleton of the fowl to obtain a general idea of the various parts (Fig 134).

VI. Examine a number of specimens (or their models) of lower chordates, fishes, reptiles and birds from the college zoological museum.

CHAPTER IX

THE RABBIT—CHARACTERS OF THE CLASS MAMMALIA—CLASSIFICATION

BEFORE examining a rabbit, as an example of the highest class of Vertebrates—the *Mammalia*, it will be well to recall the characters in which the frog, taken as an example of the class Amphibia, differs from a fish and resembles the reptiles, birds, and mammals (see p. 420), as also the points which these three classes have in common and in which they differ from a frog (see p. 453). The Mammal, again, differs from all other vertebrates in many important respects, some of the more obvious of which are:—the presence of an *epidermic* exoskeleton consisting of *hairs;* the high temperature of the blood, which remains almost uniformly within a few degrees of 100° Fahr., and does not vary to any appreciable extent with the temperature of the air; the presence of *mammary glands* beneath the skin in the female which secrete milk for nourishing the young. In the large majority of Mammals, the teeth are differentiated into front-teeth for biting or seizing the food and cheek-teeth or grinders, and their succession is limited to two functional sets; an external ear or *pinna* is present; there is no cloaca, the anus and urinogenital apertures opening separately on the

exterior. The other important characters will be summed up after we have examined the structure of the rabbit in detail.

External Characters.—The rabbit (*Lepus cuniculus*) is a very abundant and widely distributed animal which in the wild state makes burrows in the earth, and the practically hairless young are born in these or in special nests. There are a number of varieties, the habits and general appearance of which have been modified by domestication (compare p. 632).

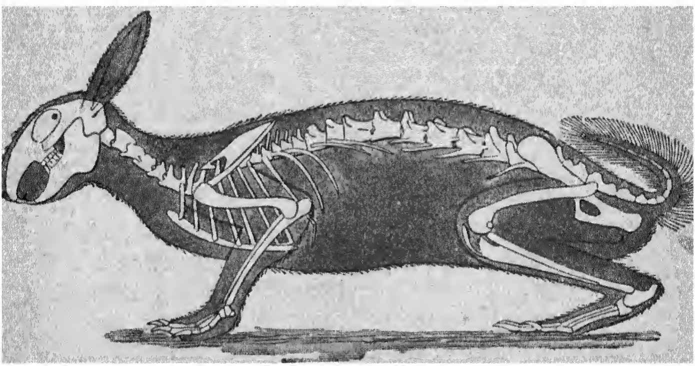


Fig 136.—Lateral view of skeleton of Rabbit with outline of body (× ¼.
(From Parker and Haswell's *Zoology*)

In addition to *head, trunk,* and short *tail,* the rabbit possesses a distinct *neck,* and the whole animal, including the limbs and even the soles of the feet, is covered with a soft fur consisting of *hairs* (Fig. 149). In the wild rabbit, the fur is of a brownish colour, lighter below, and white under the tail: in the many domesticated varieties the colour is very varied.

The hairs correspond to modified epidermic cells which become converted into a horny material; they are developed in tube-like involutions of the epidermis called *hair-sacs,* into the swollen base of each of which a mesodermal *hair-papilla*

projects, the substance of the hair, with its *cortex* and *medulla*, being formed from the epidermic cells covering the papilla (Fig. 149). Into the hair-sacs open the ducts of *sebaceous glands* (D) the secretion of which serves to lubricate the hairs.

There are five digits in the hand or *manus*, and four in the foot or *pes*, each terminated by a pointed and curved horny *claw*, developed, like the hairs, from the epidermis. Along the ventral surface of the body in the female are four or five pairs of papillæ—the *teats*, on

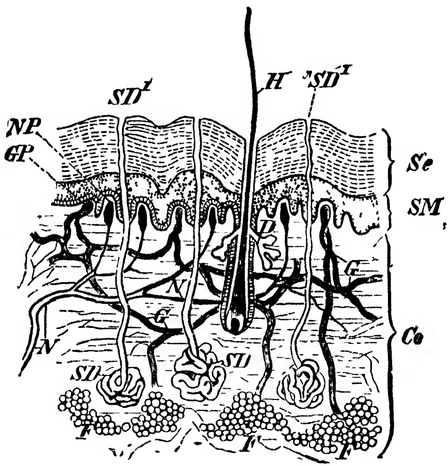


FIG. 137 —Section through the Human Skin
Co derm; *F.* subcutaneous fat, *GP* vascular papillæ; *H* hair with sebaceous glands (*D*); *N* and *G* nerves; *NP* sensory papillæ, *Se* stratum corneum; *Sd* sweat-glands, with their ducts (*SD'*); *Sm* stratum Malpighii. (After Weidersheim)

which open the ducts of the milk-glands, which correspond to modified integumentary glands. The various parts of the skeleton (Fig. 148) can be felt through the skin, and it will be noticed that the anterior part of the trunk, or *thorax*, is surrounded by *ribs*, many of which meet below with a breast-bone or *sternum*, and which are absent in the posterior part of the trunk, or *abdomen*.

Beneath the anterior end of the snout is the transverse *mouth*, which has a narrow gape and is bounded by upper and lower *lips*: the upper lip is divided by a longitudinal cleft which is continuous with the oblique, slit-like *external nostrils*. Just inside the lips are the upper and lower front teeth or *incisors*, which are chisel-shaped, and behind them the hairy integument is continued on either side into the cavity of the mouth. The *eyes* are protected by movable hairy *upper* and *lower eyelids*, as well as by a hairless third eyelid or *nictitating membrane* (compare p. 430), supported by cartilage and situated in the anterior corner of the eye, over which it can be partly drawn: it corresponds to the little red lump in the inner corner of the human eye. On the upper lip and above and below the eye are certain very long and stiff hairs—the "whiskers" or *vibrissæ*, and behind the eyes are a pair of long and movable *external ears* or *pinnæ*: these are supported by cartilage and are somewhat spout-shaped, leading to the external auditory openings.

Below the root of the tail is the *anus*, and in front of and below this the *urinogenital aperture*, the space between them being known as the *perineum*. On either side of these apertures is a hairless depression of the skin on which open the ducts of the *perineal glands*, the secretion of which has a strong and characteristic odour. In the female the slit-like urinogenital aperture is called the *vulva*; in the male the aperture is smaller and is situated on the conical apex of a cylindrical organ, the *penis*, which can be retracted within a fold of skin, the foreskin or *prepuce*. On either side of the penis is an oval pouch of the skin, the *scrotal sac*, not very apparent in young animals, in each of which a *spermary* or *testis* is contained.

Skeleton.—The skeleton of the adult rabbit consists almost entirely of bone, but it must be remembered that,

in addition to certain cartilages described below, all articular surfaces are covered or lined by a thin layer of cartilage, and that the various parts of the skeleton are connected together by ligaments.

In the **skull**, both replacing and investing bones (p. 45) are much more numerous than in the frog, and the structure of the entire skull is far more complicated and highly differentiated. A posterior, relatively large *cranial region*, in the side walls of which the auditory capsules are embedded, can be distinguished from an anterior, somewhat conical *facial region*, constituting the skeleton of the snout (Fig. 138). Just behind the junction of these two regions on either side is a large *orbit*, separated from its fellow by a thin *interorbital septum*, perforated by a foramen for the optic nerve (*opt. fo*).

At the sides of the *foramen magnum* are the two rounded *occipital condyles;* the *auditory apertures* (*aud. me*) are situated at the sides of the posterior part of the cranium, and the *external nostrils* open at the anterior end of the snout. Most of the bones remain more or less distinct throughout life, and are in contact along lines or *sutures*, many of which are wavy or zig-zagged: others, again, become completely fused in the adult, so that their limits are no longer distinguishable.

The *upper jaw* forms part of the facial region, which encloses the olfactory chambers; and the *lower jaw*, consisting of a single bone on either side, articulates directly with the sides of the cranium without the intervention of a hyomandibular as in the dogfish (p. 421) or of a quadrate cartilage as in the frog (p. 46). The rest of the visceral portion of the skull, representing the hyoid and first branchial arch, forms the so-called *hyoid* bone, which is embedded in the base of the tongue (Fig. 149, *hy*).

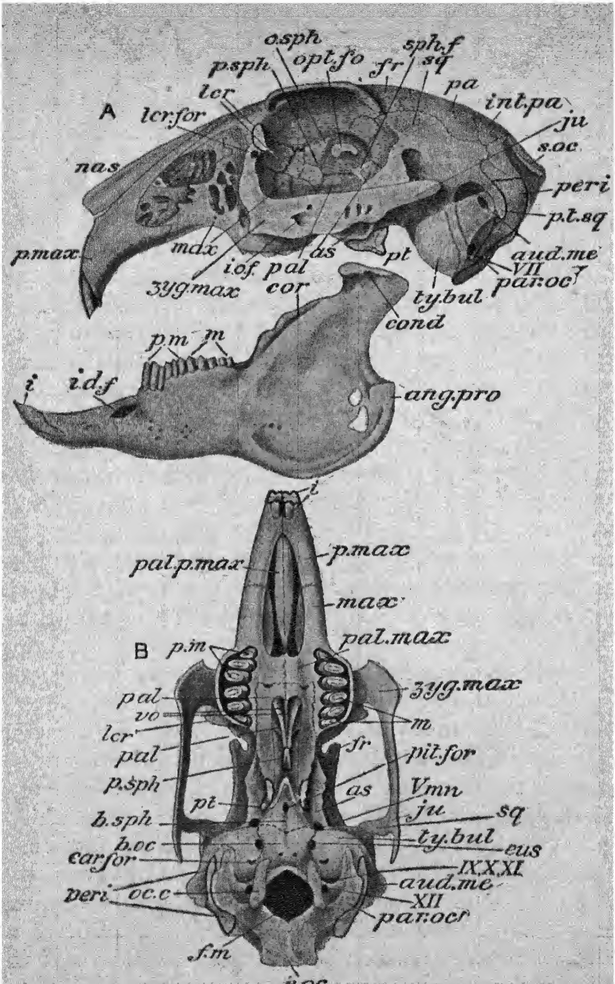


FIG 138 —Skull of Rabbit (Nat size) A, lateral view with lower jaw; B, ventral view

ang proc angular process of mandible, *as* alisphenoid (external pterygoid process below), *aud me* external auditory aperture in tympanic bone, *b oc* basioccipital, *b sph* basisphenoid, *cond* condyle of lower jaw, *car for* foramen for internal carotid artery; *eus* Eustachian canal, *f m* foramen magnum; *cor* coronoid process; *fr* frontal; *i* incisors; *i. d. f.* inferior dental foramen

for passage of the mandibular division of the trigeminal nerve, *int pa.* interparietal, *i o f* infraorbital foramen for passage of the maxillary division of the trigeminal nerve, *ju* jugal, *lcr* lacrymal, *lcr for.* lacrymal foramen, *m.* molars, *max* maxilla, *nas* nasal, *oc c.* occipital condyle, *opt fo* optic foramen; *o sph* orbitosphenoid, *pa.* parietal, *pal.* palatine, *pm.* premolars; *pal max* palatine process of maxilla, *par oc.* paroccipital process of exoccipital; *pal p max* palatine process of premaxilla, *p max.* premaxilla; *peri* periotic; *pit for* pituitary foramen; *p sph* presphenoid, *pt.* pterygoid; *p t sq* post-tympanic process of squamosal, *s oc* supraoccipital; *sph f* sphenoidal fissure, *sq* squamosal, *ty bul* tympanic bulla, *vo.* vomer, *zyg max* zygomatic process of maxilla, *V. mn.* foramen for mandibular division of trigeminal nerve, *VII.* for facial nerve, *IX X XI* for glossopharyngeal, vagus, and spinal accessory, *XII* for hypoglossal (From Parker and Haswell's *Zoology*)

The bones[1] which form the walls of the brain-case are arranged in three rings or segments, the middle and posterior of which are separated by the auditory capsules (Figs. 138 and 139 A, *peri*).

The posterior, or *occipital segment*, consists of four bones, which in the adult become completely united with one another. The lower of these is the *basioccipital* (*b. oc*), a flattened bone bounding the foramen magnum below, and forming the hinder part of the base of the skull and the lower part of each occipital condyle (*oc. c*). The two *exoccipitals* (*e. oc*) bound the foramen magnum at the sides, and form the upper part of the occipital condyles: each is produced downwards into a *paroccipital process* (*par. oc*) which fits closely against the posterior surface of a swollen bone (*ty. bul*) to be described presently, which is continuous with a tube surrounding the auditory aperture (*aud. me*). The occipital segment is completed above by the *supraoccipital* (*s. oc*), bounding the foramen magnum above; it has a pitted surface and is marked externally by a shield-shaped prominence.

The middle, or *parietal segment*, consists of five bones—a *basisphenoid* (*b. sph*) below, an *alisphenoid* (*a. sph, as*) on either side, and two *parietals** (*pa*) above. The broad posterior end of the basisphenoid is connected with the basioccipital by a thin plate of cartilage, and tapers in front to a blunt point: it is perforated at about

[1] In the following description, the investing bones are distinguished by an asterisk from the replacing bones (see p. 45).

its middle by an oval *pituitary foramen,* and on its upper surface is hollowed out to form a depression in which the pituitary body lies (*s.t*). The alisphenoids are wing-like bones, directed upwards and outwards, and firmly united with the basisphenoid: each is produced ventrally into a *pterygoid process* (*as*), consisting of two laminæ which converge and unite with one another anteriorly. The parietals are a pair of thin, slightly

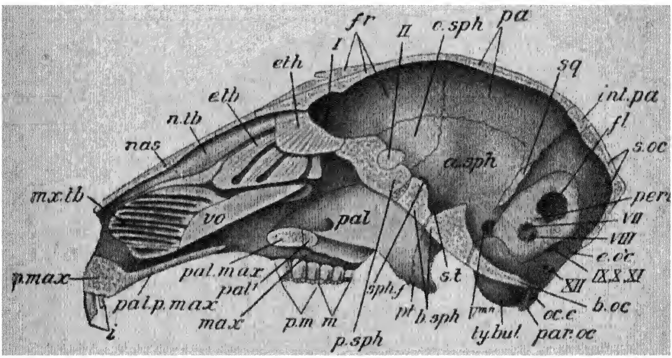


FIG. 139—Skull of Rabbit in longitudinal vertical section (Nat size.) The cartilaginous nasal septum is removed

a sph alisphenoid, *e oc* exoccipital, *e tb.* ethmo turbinal, *eth* ethmoid; *fl* fossa for flocculus of brain, *i* incisors; *mx tb* maxillo-turbinal, *n tb* naso-turbinal, *pal'* palatine portion of the bony palate, *p. sph* presphenoid, *s. t.* sella turcica, or depression in which the pituitary body lies, I, region at which the olfactory nerves leave the skull; II, optic foramen, V *mn* foramen for mandibular division of trigeminal, VII, for facial nerve; VIII, for auditory nerve; IX, X, XI, for glossopharyngeal, vagus, and spinal accessory, XII, for hypoglossal Other letters as in Fig 150.

arched bones forming a considerable part of the roof of the brain-case and united with one another by suture along the middle line; the outer edge of each gives off a thin, ventral process which is covered by the squamosal (*sq*), a bone which will be referred to presently (p. 453) and which separates the parietal from the alisphenoid. Interposed between the parietals and the supraoccipital is a small median *interparietal** (*int. pa*).

The *frontal segment* also consists of five bones—a *presphenoid* (*p. sph*), two *orbitosphenoids* (*o. sph*), and two *frontals** (*fr*). The small presphenoid is laterally compressed and is connected with the basisphenoid by cartilage, so that in the dry skull there is a considerable interval between the two bones; it forms the inferior and anterior boundary of the optic foramen (*opt. fo*, II), which puts the two orbits in communication with one another and both in communication with the cranial cavity. The orbitosphenoids are two wing-like laminæ directed outwards and slightly backwards, and completely fused with the presphenoid; they surround the rest of the optic foramen. The frontals form the roof and side-walls of the anterior part of the brain-case, and are united by suture with one another in the middle line and with the parietals behind; below they meet with one another anteriorly on the floor of the brain-case and unite with the presphenoid by suture; the outer part of each forms a prominent crescentic ridge, the *supra-orbital process*.

The brain-case is closed in anteriorly by a bone riddled with numerous small holes for the passage of the olfactory nerves (I): this is the *cribriform plate* of the *ethmoid* (*eth*).

It will be remembered that in the frog the occipital region is ossified by exoccipitals only, the parietals and frontals of either side are fused, there are no ali- or orbito-sphenoids, the cartilaginous walls of the anterior part of the cranium are ossified as a sphenethmoid, and that the floor of the skull is supported by an investing bone, the parasphenoid (pp. 42-43).

The auditory capsules are comparatively loosely wedged in laterally between the parietal and occipital segments; in the embryo each is ossified from three centres, instead of one (the pro-otic) as in the frog, but these early unite to form the *periotic bone* (*peri*), as the

ossified auditory capsule is called. The internal or *petrous* portion of this bone (Fig. 139) encloses the membranous labyrinth of the ear and is very dense and hard; posteriorly it is produced outwards as the porous *mastoid* portion, which is visible on the outer side of the skull (Fig. 138, A). Closely applied to the outer surface of each periotic is a bone called the *tympanic*,* consisting of a tubular portion above—the edge of which surrounds the auditory opening (*aud. me*) to which the cartilage of the pinna is attached, and of a swollen portion, or *tympanic bulla* (*ty. bul*), below: this encloses the tympanic cavity, and in it, at the base of the tubular portion, is an incomplete bony ring to which the tympanic membrane is attached (Fig. 138). The tympanic is incomplete on its inner side, where its cavity is closed by the outer wall of the periotic, and between the two, at the antero-inferior angle of the former, is the aperture by which the Eustachian tube leaves the tympanic cavity (compare p. 17). When the tympanic is removed, two small holes are seen on the outer wall of the periotic: the anterior of them is the *fenestra ovalis* and is plugged by the *stapes*—which, together with two small bones, the *malleus* and *incus* (Fig. 161), forms the chain of *auditory ossicles* to be described later in connection with the organ of hearing; the posterior aperture is called the *fenestra rotunda*. On the internal or cranial surface of the periotic is a large depression (*fl*) which lodges the flocculus of the cerebellum (Fig. 158).

The olfactory capsules are roofed in by two long and narrow *nasal bones** (*nas*), which meet together in the middle line and unite by suture with the frontals posteriorly. Their side walls are formed by the bones which bear the teeth of the upper jaw—the *premaxillæ** (*p. max*) and *maxillæ** (*max*), and in the median line

below is a single long and slender bone, deeply grooved on its upper surface, and formed by the fusion of the two *vomers** (*vo*). The two nasal chambers are separated from one another in the middle line by a median vertical plate of cartilage, the *nasal septum* (Fig. 149, *n. s*), embraced below by the vomers. This cartilage, together with the cribriform plate and a median vertical plate of bone (*eth*) extending forwards from the latter into the septum, constitutes the *mesethmoid*. Within the nasal chambers certain scroll-like folds of the mucous membrane (Fig. 149) are present in order to increase the surface, and in these cartilages are developed. The cartilages become ossified, and the resulting *turbinal bones* unite with certain of the bones enclosing the olfactory organs, and are named accordingly. The *ethmo-turbinals* (Fig. 139, *e. tb*), or true olfactory scrolls, are two complicated, folded bones united to the cribriform plate of the ethmoid, and are covered in the fresh condition by the olfactory epithelium; the *maxillo-turbinals* (*mx. tb*) are similar but more complex bones in the antero-ventral part of the nasal cavities; and the *naso-turbinals* (*n. tb*) are thin, folded bones, much less complex, and fused with the inferior surface of the nasals.

In the front wall of each orbit, fitting comparatively loosely between the frontal and maxilla, is a small bone, the *lacrymal** (Fig. 138, A, *lcr*), with a notch near its outer border through which the naso-lacrymal duct passes (p. 198).

As in the frog, the chief bones of the upper jaw on either side are the *premaxilla** (*p. max*) and the *maxilla** (*max*), and nearer the middle line are the *palatine** (*pal*) and "*pterygoid*"* (*pt*): in the embryo the position of the two last-mentioned bones is taken by cartilage representing the upper jaw of the dogfish (compare

Figs 125 and 10) The premaxillæ, in which the sockets for the front or incisor teeth are situated, form the anterior boundary of the snout, and articulate with one another in the median line and with the maxilla behind: each gives off a *nasal process* passing backwards between the nasal and maxilla to the frontal, and a *palatine process* (*pal. p. max*) extending backwards along the palate in contact with its fellow of the opposite side. The maxillæ are large and irregular bones, parts of the sides of which are fenestrated, and in which the cheek-teeth are situated. From the inner and inferior edge of each, opposite the first two cheek-teeth, a horizontal *palatine process* (*pal. max*) is given off, which, articulating with its fellow of the opposite side, forms the anterior part of the bony support of the hard palate—this is of much less extent in the rabbit than in most mammals: from its outer side arises a *zygomatic process* (*zyg. max*), which forms the anterior part of the strong *zygomatic arch* extending below and externally to the orbit.

The palatines are thin, nearly vertical, bony laminæ, internal to the maxillæ to which they are attached in front, while above they join the presphenoid and the pterygoid process of the alisphenoid. They bound the passage of the internal nostrils, and from the inner and anterior region of each is given off, opposite the third cheek-tooth, a horizontal, inwardly directed process (*pal*^{1}), which, articulating in the middle line with its fellow of the opposite side and in front with the palatine process of the maxilla, forms the posterior part of the bony support of the hard palate. The bones usually known as pterygoids are small irregular plates attached to the posterior edge of the corresponding palatine and the pterygoid process of the alisphenoid; each ends ventrally in a backwardly curved process.

The *squamosals** (*sq*) are a pair of plates which overlap and complete the side-walls of the brain-case (p. 448) in front of the periotics: they articulate with the frontals, parietals, orbitosphenoids, and alisphenoids. From the outer face of each is given off a strong *zygomatic process*, which bears on its under surface the articular facet for the lower jaw, and further back a slender process (*p. t. sq*) arises which is applied to the outer surface of the periotic.

The zygomatic processes of the squamosal and maxilla respectively are united by a flat bar of bone, the *jugal** (*ju*), which in the adult is fused with the latter. All these three bones therefore take part in forming the zygomatic arch.

Most of the apertures for the transmission of the cerebral nerves have so far not been mentioned: the branches of the olfactory nerve, as we have seen, pass out through the numerous apertures in the cribriform plate (Fig 139, *eth*, I), and the optic foramen (*opt. fo*, II) is situated between the orbitosphenoid and presphenoid. Behind and below the optic foramen is a vertical aperture—the *sphenoidal fissure* (*sph f*)—between the basisphenoid and alisphenoid, which transmits the third, fourth, and sixth nerves, as well as the ophthalmic and maxillary divisions of the fifth. Between the periotic and alisphenoid is a large space (V *mn*), through the anterior part of which the mandibular division of the trigeminal leaves the skull.[1] Between the mastoid portion of the periotic and the posterior border of the tympanic, at the junction of the tubular and bulbous portions of the latter bone, is a small aperture—the *stylomastoid foramen*, which transmits the seventh nerve: this and the eighth (VII, VIII) enter the periotic just below the depression for the flocculus of the cerebellum (*fl*). A space (IX, X, XI) between the occipital condyle and tympanic bulla gives exit to the ninth and tenth, as well as to the eleventh—which is not represented as a distinct nerve in the dogfish and frog;

[1] In many Mammals (*e.g.*, dog, cat) the maxillary division of the trigeminal passes out through a separate foramen, behind the sphenoidal fissure; and the anterior part of the space referred to above is separated off as a distinct foramen for the mandibular division.

and the hypoglossal (p. 169), which in Mammals is counted as the twelfth cerebral nerve, passes out through two small apertures (XII) in the exoccipital, just anterior to the condyle. Various other apertures will be noticed in the skull and jaws: through some of these branches of certain of the above-mentioned nerves pass, while others transmit blood-vessels.

The lower jaw or *mandible* (Fig. 138, A) consists of two halves or rami, each corresponding essentially to the dentary of the frog, which unite with one another in front, at the symphysis, by a rough surface, while behind they diverge like the limbs of the letter V. Each ramus is a vertical plate of bone, broad behind and tapering towards the front, where it bears the incisor teeth: further back, on its upper margin, are the sockets for the cheek-teeth, and behind them is an ascending portion which bears the *condyle* (*cond*) for articulation with the facet on the squamosal: in front of the condyle is a curved *coronoid process* (*cor*). The postero-inferior border, which is rounded and inflected, is known as the *angular process* (*ang. pro*).

The *hyoid* is a small bone situated at the root of the tongue, anterior to the larynx (Fig. 149, *hy*). It consists of a stout body or *basi-hyal*, a pair of small anterior horns, representing the ventral ends of the hyoid arch of lower Vertebrates, and a pair of longer, backwardly projecting posterior horns or *thyro-hyals*, attached to the larynx and representing the lower ends of the first branchial arch (compare p. 420).

The **vertebral column** includes about forty-five bony vertebræ, each consisting of a centrum, a neural arch, and various processes (compare pp. 36–39), but becoming simplified towards the end of the tail. The centra have flat anterior and posterior surfaces, and are not connected by synovial articulations, as in the frog, but interposed between them are elastic *intervertebral discs* of fibro-

cartilage. In addition to the ossification which gives rise to the main part of the centrum, a separate flat disc of bone (Fig. 140, *ep*) is formed on the anterior and posterior surface of each. These *epiphyses* are characteristic of the vertebræ of all or nearly all Mammals: they unite comparatively late with the centrum proper, and so in disarticulated skeletons of young animals they often come away from the main mass of the centrum and remain attached to the intervertebral discs.

In correspondence with the differentiation of the parts of the body, the vertebral column is divisible into five regions (Fig. 136): the *cervical* in the neck, including seven vertebræ, the first two of which—called respectively the *atlas* and *axis*—are peculiarly modified in order to allow the skull free movement; the *thoracic* in the thorax, twelve or thirteen in number, and bearing *ribs*; seven or six *lumbar* in the abdominal region; three or four *sacral* in the sacral region; and about fifteen or sixteen *caudal* in the tail.

Examining one of the anterior thoracic vertebræ first (Fig. 140), we see that the *centrum* (*c*) is continuous above with the *neural arch* (*n. a*), the lower part of which, on either side, presents an anterior and a posterior notch (*i. v. n*), so that when the vertebræ are in their natural position, an *intervertebral foramen* is formed for the passage of a spinal nerve. The roof of the arch is continued into a long *neural spine* (*n. sp*) projecting upwards and backwards, and just above the intervertebral notches are a pair of anterior and posterior *articular processes* or *zygapophyses* (*pr. z, pt. z*), which articulate synovially with the vertebræ next in front and behind respectively. The articular surface of each pre-zygapophysis looks upwards and inwards, that of the post-zygapophysis downwards and outwards. Arising laterally from either side of the arch is an outstanding *transverse process* (*t. pr*), on the under surface of which is an articular *tubercular facet* (*t. f*), with which the upper fork of the rib (p. 458) articulates. The lower fork or *head* of the rib articulates with a facet (*c. f*) formed partly by the anterior edge of the corresponding centrum just at the base of the neural arch, and partly by the posterior edge of

the centrum next in front, so that each centrum bears half a *capitular facet*, as it is called, on either side, both anteriorly and posteriorly (*c. f′*, *c. f″*). There are no free ribs in the vertebræ of other regions, in which, however, they are represented in the embryo, but early fuse with the corresponding transverse processes.

The first *cervical* vertebra, or *atlas* (Fig. 141, A), is ring-shaped, and its lower portion is narrow and unlike the other centra The neural spine is small, and the transverse processes are broad horizontal plates, each perforated at its base by a *vertebrarterial canal* through which the vertebral artery runs On the anterior face of the lateral parts of the atlas are two concave articular facets for articulation with the occipital condyles of the skull, and on its posterior face are two small facets for articulation with the second vertebra. The second cervical vertebra, or *axis* (Fig. 141, B), has its centrum produced anteriorly into a conical *odontoid process*, which fits into the lower part of the ring of the atlas and is held in its place by a ligament extending transversely across the latter: it is ossified from a distinct centre, which really belongs to the centrum of the atlas. The neural spine of the axis is elongated and compressed, and its transverse processes small and perforated each by a vertebrarterial canal; zygapophyses are present only on the posterior face of the arch. In all the other cervical vertebræ (Fig. 141, C), the transverse processes are also perforated by vertebrarterial canals, and, except in the seventh or last, are divided into dorsal and ventral lamellæ. The zygapophyses resemble those of the thoracic vertebra described above. The seventh cervical vertebra has a longer spine than the others, and bears a pair of half facets on the posterior surface

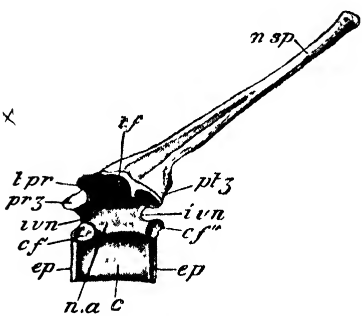


FIG. 140.—Fifth thoracic vertebra of the Rabbit, from the left side (× 1½) *c* centrum; *c f′* capitular half-facet for fifth and *c f″* for sixth rib; *ep.* epiphysis *i. v n* intervertebral notch; *n a* neural arch; *n sp.* neural spine, *pr z* pre-zygapophysis; *pt. z.* post-zygapophysis; *t. f.* tubercular facet for fifth rib, *t pr.* transverse process.

of its centrum with which the first pair of ribs in part articulate.

A typical *thoracic* vertebra has already been described. In the tenth, the neural spine is vertical, and in the remaining two or three, which are larger than the others, it slopes

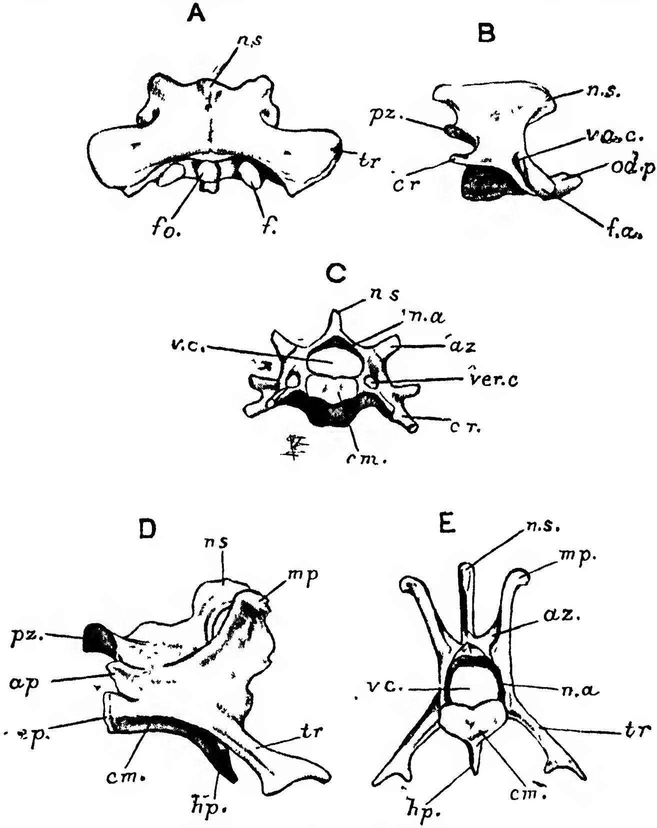


FIG 141.—Selected vertebræ of Rabbit

A, Atlas, from the dorsal surface, *B*, Axis, from the right side, *C*, one of the middle cervical vertebræ, anterior aspect; *D*, second lumbar vertebra, from the right side; *E*, the same, anterior aspect; *ap* anapophysis, *c r.* cervical rib; *f.* articular surfaces for the axis; *fa.* articular surfaces for the atlas; *fo* facet for odontoid process; *hp.* hypapophysis; *mp* metapophysis; *od. p* odontoid process; *va. c.* vertebrarterial canal. Other letters as in the previous figure.

forwards. In the posterior three or four there are no tubercular facets, the ribs in this region not being forked; the capitular facets are entire, and are situated on the corresponding centrum only. Additional processes are present above the pre-zygapophyses from the ninth thoracic vertebra onwards

The *lumbar* vertebræ (Fig 141, D and E) are relatively large, increasing in size from before backwards, and their various processes are greatly developed. The neural spines are directed upwards and forwards, the transverse processes are large and project outwards, downwards and forwards As in the posterior thoracic vertebræ, there are stout processes above the pre-zygapophyses (which face *inwards*), and there is also a pair of more slender processes below the post-zygapophyses (which face *outwards*), and a median ventral process projecting downwards from the centrum in the first two.

The *sacral* vertebræ are fused to form the *sacrum* (Fig. 145, *sacr*), which supports the pelvic arch. The first —and to a less extent the second also—has large, expanded, transverse processes which articulate with the ilia; these are the sacral vertebræ proper; the others, which decrease in size from before backwards, are really the anterior caudal vertebræ which fuse with the true sacral vertebræ to form a *compound sacrum.*

The more anterior *caudal* vertebræ resemble those of the sacral region, but on passing backwards all the processes are seen to diminish in size, until nothing but the centra are left at the end of the tail.

There are twelve or occasionally thirteen pairs of **ribs**, which have the form of curved rods, situated in the walls of the thorax, and articulating with the thoracic vertebræ above and—in the case of the first seven—with the breast-bone or sternum below: the remaining ribs do not reach the sternum (Fig. 142).

Each rib consists of a bony, dorsal *vertebral portion,* and of a ventral, *sternal portion* consisting of cartilage which is calcified or only incompletely ossified. The dorsal end—the head or *capitulum* of the rib—articulates with the capitular facets on the centra, and the first nine have also a *tubercle,* a short distance from the capitulum, which articulates with the tubercular facet; just externally to the tubercle is a short, vertical process.

The **sternum** (Fig. 142), which is developed in the embryo by the fusion of the ventral ends of the ribs (and therefore has a different morphological significance from the sternum of Amphibians, see p. 50), consists of six segments or *sternebræ*, the first of which, or *manu-*

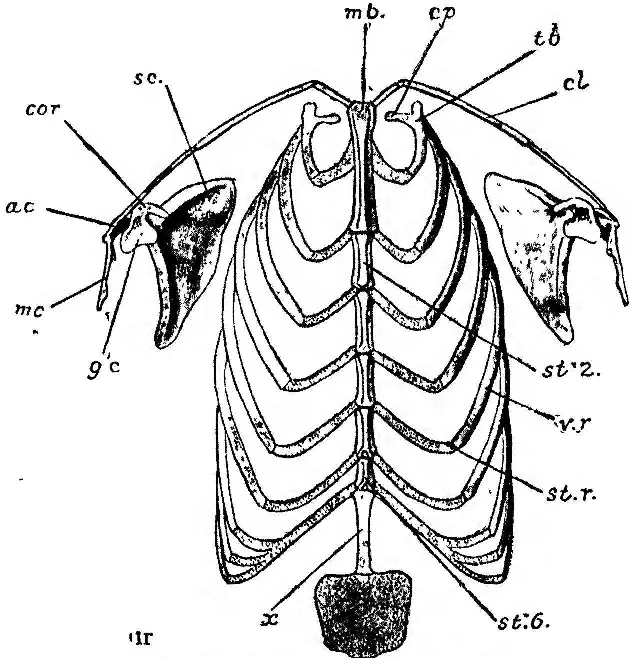


FIG. 142.—Sternum and pectoral arch of Rabbit, ventral aspect. *ac.* acromion, *cl.* clavicle; *cor.* coracoid process; *cp* capitulum; *g c.* glenoid cavity; *mb.* manubrium, *mc* metacromion; *sc* scapula, *st.* 6. sixth sternebra, *st r* sternal portion of a rib, *tb* tuberculum; *v r* vertebral portion of a rib; *x.* xiphisternum with its cartilaginous plate. (After Borradaille)

brium (*mb*), is larger than the rest, and has a ventral keel. With the last is connected a rounded, horizontal, cartilaginous plate, the ***xiphisternum***. The ribs articulate between the successive sternebræ except in the

case of the first pair, the articulations of which are on the manubrium.

The chief bone of the **pectoral arch** is the flat, triangular *scapula* (Fig. 142, *sc*), the coracoid portion (compare p. 50) becoming early fused with it and forming a small, inwardly curved *coracoid process* (*cor*), situated anteriorly to the glenoid cavity at the lower end or apex of the scapula: the apex lies over against the first rib, and the bone inclines upwards and backwards to its dorsal base, which in the fresh condition consists of a strip of cartilage, the *supra-scapula*. On its outer surface is a prominent ridge or *spine*, the free ventral edge of which is called the *acromion* (*ac*), from which a process, the *metacromion* (*mc*), projects backwards. The collar-bone or *clavicle* is never strongly developed in Mammals in which the fore-limb only moves in one plane—forwards and backwards: in the rabbit it is a small, curved, rod-like bone, attached by fibrous tissue at one end to the sternum and at the other to the acromion process of the scapula, there being small cartilages at either end of it.

The relative positions of the bones of the **fore-limb** are at first sight somewhat difficult to understand owing to their having become altered in the course of development. In your own fore-arm the bones can be rotated on one another, so that the thumb can be made to point outwards or inwards: while in the rabbit the first digit has permanently the same position, pointing inwards. To understand this, extend your arm outwards with the thumb pointing away from the ground. The back of the hand and arm, continuous with the dorsal surface of the body, or back, is its *dorsal surface*; the palm of the hand, and the surface of the arm continuous with the chest, is its *ventral surface*; the border of the arm and hand continuous with the thumb is the *preaxial border*; and that continuous with the little finger the *postaxial border*. This position is called the position of *supination*; if the fore-arm and hand be now rotated, so that the thumb points inwards, the position is that of *pronation*. While in this position, bend the elbow at right angles

and bring it inwards close to the body; the preaxial border of the hand will now be on the inner side, and an examination of the bones of the fore-arm shows that they cross one another. It is in this position that the bones of the rabbit's fore-limb are permanently fixed (Fig 136, and compare Fig. 16).

The proximal extremity of the *humerus* (Fig. 143) bears a rounded *head* (*hd*) for articulation with the glenoid cavity, in front of which is a groove for the tendon of the biceps muscle (p. 64); certain *tuberosities* for the attachment of muscles will also be observed. Its distal extremity presents a large, pulley-like surface or *trochlea* (*tr*) for the articulation of the bones of the fore-arm, and a deep depression or *fossa*, perforated by a foramen, on its posterior side, for the reception of the end of the ulna. The *radius* (Fig. 144) is the shorter, inner (preaxial) bone of the fore-arm, and is slightly curved. Its head presents a large double surface for articulation with the trochlea of the humerus, and its distal extremity a pair of slight concavities for the bones of the carpus: the shaft is flattened where it abuts against the corresponding flattened surface of the *ulna* (Fig. 144). Near the proximal end of the last-mentioned bone is a cavity for the articulation of the humerus, and proximally to this, at the elbow, the ulna is produced to form a large *olecranon process* (*o.p.*), which is received into the fossa on the humerus when the limb is extended; its small distal end articulates with the carpus.

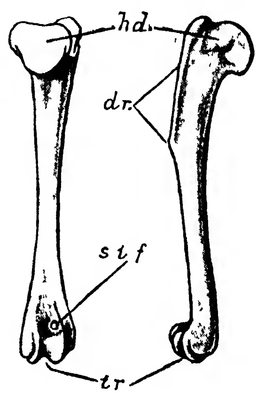


FIG 143 —Humerus of Rabbit. *d r* deltoid ridge, *hd* head; *s. t. f* supra-trochlear foramen, *tr* trochlea.

The *carpus* (Fig. 144), as in the frog (p. 52), consists of a proximal and a distal row of small, nodular bones, which articulate with one another where they are in contact. The bones of the proximal row, beginning at the inner (preaxial) side, are the *radiale* (*r*) and *intermedium* (*i*), articulating with the radius, and the *ulnare* (*u*), articulating with the ulna. In the distal row are five bones, the middle one of which is distinctly proximal to the other four, so as really to lie in the middle of the carpus: this is the *centrale*, the others constituting a row of *distal carpals*. Of these the first three articulate with the corresponding digits, the fourth, on the outer (postaxial) side, supporting the fourth and fifth digits and really consisting of two carpals fused with one another.

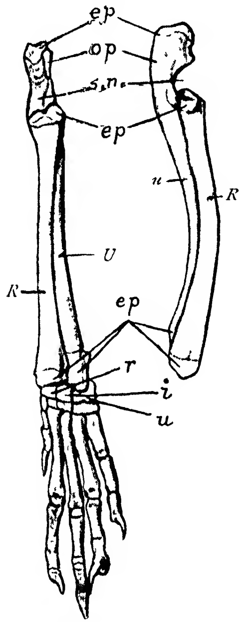


FIG. 144—Radius and Ulna, Carpals, Metacarpals, and Phalanges of Rabbit
ep epiphyses; *i* intermedium, *o. p* olecranon process; *R.* radius, *r* radiale; *s. n.* sigmoid notch; *U.* ulna, *u.* ulnare.

A small bone, the *pisiform*, articulating with the ulna and ulnare on the ventral side, is usually looked upon as a *sesamoid bone, i.e.*, an ossification in the tendon of a muscle; but it probably represents the vestige of a sixth digit.

The hand or *manus* consists of five digits, each made up of a *metacarpal* and of *phalanges*, articulating with one another. The innermost (preaxial) digit—the thumb or *pollex*—is the shortest, and the third the longest: the former has two phalanges, the others three

each, the distal or *ungual* phalanx of all the digits having a conical form, its dorsal surface being grooved for the firmer attachment of the horny claw.

The ends of the long bones in both limbs are separately ossified as *epiphyses* (compare p. 455), which eventually unite with the shaft of the bone in question. Small *sesamoid bones* are situated on the under or palmar side of the joints of the digits.

The **pelvic arch** (Fig. 145) consists of two lateral halves or *innominate bones*, the long axis of which is almost parallel with that of the vertebral column (Fig. 136), and which are firmly united anteriorly and internally with the transverse processes of the sacral vertebræ by a rough surface, while ventrally they are connected together by cartilage at the pelvic *symphysis*. On the outer surface of each innominate bone, at about the middle of its length, is a deeply concave cup, the *acetabulum*, for articulation with the head of the femur: in it, in young rabbits, a triradiate suture can be seen, marking the boundaries of the three bones of which the innominate is composed (p. 53). Of these, the antero-dorsal is the *ilium* (*il*), which is connected with the sacrum. The postero-ventral portion

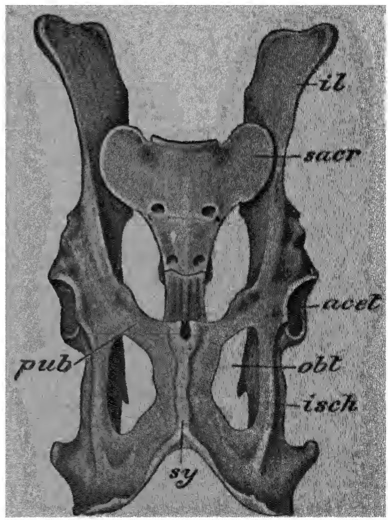


FIG. 145.—Pelvic girdle and sacrum of Rabbit, ventral aspect
acet acetabulum, *il* ileum, *isch* ischium; *obt* obturator foramen; *pu* pubis; *sacr* sacrum, *sy*. symphysis. (From Parker and Haswell's *Zoology*.)

of the innominate is perforated by a large aperture —the *obturator foramen*, through which a nerve of that name passes (p. 496), the bone above and behind it being the *ischium* (*isch.*), and that below and in front of it the *pubis* (*pu.*). Behind the obturator foramen the ischium has a thickened posterior edge or *tuberosity*, and then curves round and becomes continuous with the pubis, both bones taking part in the symphysis.

In young rabbits it will be noticed that the part of the pubis which enters the acetabulum consists of a small, distinct epiphysis.

The **hind-limb** has undergone rotation forwards (Fig. 136), so as to be brought, like the fore-limb, into a plane parallel with the median vertical plane of the body; but the rotation being forwards, and the bones of the shank not being crossed, the preaxial border is internal in the whole limb, and the original dorsal surface looks, on the whole, forwards

Close to the proximal end of the *femur* (Fig. 146), on its inner (preaxial) border, is a rounded projecting *head* (*hd*) for articulation with the acetabulum: the actual end of the bone is formed by a strong process, the *great trochanter* (*tr.* 1), while just distal to the head is a *lesser trochanter* (*tr.* 2), and opposite this, on the outer (postaxial) side, a *third trochanter* (*tr.* 3). The distal end of the bone bears two large *condyles*, separated from one another by a notch, for articulation with the tibia: this notch is continuous with a groove extending for a short distance along the anterior (dorsal) surface of the femur in which a large sesamoid bone (p. 462), the knee-cap or *patella*, slides: the patella lies in the tendon of the extensor muscles of the leg, and is connected by ligament with the tibia. Two other sesamoid bones, the *fabellæ*, occur on the opposite side of the knee-joint.

The *tibia* (Fig. 146, T), or inner (preaxial) bone of the shank, is much larger than the *fibula* (Fig. 146, F), the

distal half of which in the adult becomes completely fused with it. The proximal end of the tibia bears two slightly concave articular surfaces for the condyles of the femur, and distally it articulates with the tarsus: a prominent ridge—the *cnemial crest*—extends along the proximal end of its anterior (dorsal) surface. The slender fibula is attached proximally to the tibia.

The *tarsus* (Fig. 147) consists of six bones arranged in three rows. In the proximal row (compare p. 54) are two tarsals, of which the inner (preaxial) or *astragalus* (*t*) — probably corresponding to two bones fused together, the *tibiale* and *intermedium* — has a large pulley-like surface for articulation with the tibia; while the outer (postaxial) *calcaneum* or *fibulare* (*f*.) articulates with the fused end of the fibula, and is produced into a strong heel or *calcaneal process*. In the middle row is a single bone, the *centrale* (*navicular*) of the tarsus, and the distal row is made up of three bones, the true first, together with the corresponding digit (*hallux*), being absent as a distinct bone. The second (apparent first) distal tarsal articulates proximally with the centrale, and distally with the innermost (preaxial) metatarsal: the

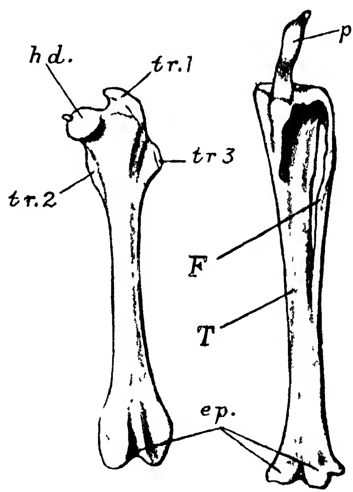


FIG. 146.—Femur, Tibia, and Fibula of Rabbit
ep epiphysis; F fibula; *hd* head; T. tibia; *tr* 1, greater trochanter; *tr* 2, lesser trochanter; *tr.* 3, third trochanter.

third (apparent second) with the centrale and the corresponding metatarsal: the fourth (apparent third), which corresponds to the two fused outer (postaxial) tarsals, with the centrale, calcaneum, and the remaining two digits.

The foot or *pes* (Fig 147) consists of four *metatarsals* with their *phalanges*, of which there are three to each digit. The metatarsal of the hallux, together with the corresponding distal tarsal, is probably represented by a distinct ossification which in the adult becomes fused with the second (apparent first) metatarsal, and forms a process on that bone which articulates with the centrale. The phalanges are similar to those of the manus, and sesamoid bones are also present on the under surface of the foot.

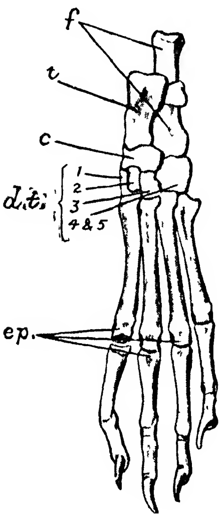


FIG 147.—Tarsals, Metatarsals, and Phalanges of Rabbit.
c. centrale, *d t* 1, 2, 3, 4, and 5, distal tarsals; *ep* epiphyses; *f.* fibulare (or calcaneum); *t.* tibiale (or astragalus)

Muscles and Body-wall:—It will be remembered that in the lancelet and dogfish the muscles of the trunk are divided up into myomeres (p. 414), while in the adult frog the only indication of such a segmentation of the muscles is seen in the recti of the abdomen. In the rabbit nearly all trace of a segmentation of the muscles has also disappeared, and the muscular system, although similar in its general arrangement to that of the frog (compare Fig. 3), is more highly differentiated and complicated. We shall have occasion to notice certain of the muscles in the course of our examination of other organs.

Immediately beneath the skin, which consists of epidermis and dermis (Fig. 137), the whole ventral region of the trunk and neck is covered by a thin *cutaneous muscle*, by means of which the rabbit is able to twitch its skin. Internally to this muscle in the female are the *mammary glands* (p. 441), which, when secreting, appear as whitish branched masses, the ducts of which can be traced to the *teats*, on the apices of which they open by numerous small apertures.

A whitish band of connective-tissue passes along the mid-ventral line of the abdomen from the xiphisternum to the pubis: this separates two longitudinal bands of muscle, the *recti abdominis*, from one another; and laterally to them, the abdominal wall consists of three thin layers of muscle with their fibres running in different directions—the *external oblique*, the *internal oblique*, and the *transversalis*, the latter being lined on its inner surface by the peritoneum. A fibrous cord, known as *Poupart's ligament*, beneath which the blood-vessels and nerves pass outwards to the leg, extends upwards and forwards from each pubis to the corresponding ilium. In the thorax the muscles of the body-wall are broken up into separate portions by the ribs, and thus form a series of *intercostal muscles*, which, like the oblique muscles of the abdomen, are arranged in two layers, external and internal, and are important in respiration.

Extending from the thorax to the fore-limb of either side are the large *pectoral muscles*; and a number of other muscles can be seen in the neck, in the ventral middle line of which, covered by the cutaneous muscle, the windpipe or *trachea* is visible (Fig. 149). The trachea is strengthened by a series of cartilaginous rings and ends in front in the *larynx*, situated between the two rami of the mandible; and just in front of the larynx is the hyoid bone (p. 454), embedded in a mass of muscle.

The Cœlome and its Contents.—On cutting open the body-cavity (Fig. 148), it will be seen to be divided into two main chambers—the *thoracic* and *abdominal cavities*—by means of the *diaphragm* (Fig. 148, B). The relatively

small thorax—which is lined by a serous membrane corresponding to the peritoneum of the abdomen and known

FIG. 148—The viscera of a Rabbit as seen upon simply opening the cavities of the thorax and abdomen

A cavity of the thorax, *B* diaphragm, *C* ventricles of heart, *D* auricles of heart, *E* pulmonary artery, *F* aorta, *G* lungs, collapsed, *H* part of pleura, *I* cartilage at end of sternum, *K* portion of body-wall left between thorax and abdomen, *a* cut ends of ribs, *L* liver, *M* stomach, *N* duodenum, *O* small intestine, *P*. cæcum; *Q* colon (From Foster & Shore's *Physiology*)

as the *pleura* (*H*)—contains the lungs (*G*), as well as the heart enclosed in a pericardium, on the ventral surface of which latter is an organ known as the *thymus* (see p 430): the gullet and main blood-vessels also pass through the thorax. The abdomen encloses the greater part of the enteric canal, together with the liver (*L*) and pancreas, the spleen, and the urinogenital organs. The diaphragm is convex on its anterior side, towards the thorax: it consists of a central, thin, *tendinous portion* into which radial *muscles* are inserted. These arise from the vertebral column and posterior ribs, and are especially strong on the dorsal side, where they form two bands known as the *pillars* of the diaphragm. When the muscles contract, the diaphragm is made flatter, and thus the thoracic cavity is enlarged.

Digestive Organs.—The mouth-cavity (Fig. 149) is large, and the small gape is bounded by upper and lower *lips*, behind which are the incisor teeth (*i*). On either side of the cavity are the borders of the upper and lower jaws from which the cheek-teeth project: these are separated from the incisors by a considerable interval or *diastema*. Close behind the upper incisors are a pair of very small openings leading into the *naso-palatine canals* (*n. p. c*), which communicate with the nasal cavities but must not be confounded with the internal nostrils. The roof of the oral cavity is formed by the *palate*, the anterior part of which, or *hard palate* (*h. p*), is transversely ridged and partly supported by bone (*h. p'*, p. 490); while the posterior part, or *soft palate* (*s. p*), is smooth, its hinder, free edge forming a pendulous flap, the *velum palati*, on either side of which is an organ known as the *tonsil*, consisting of connective and lymphoid tissue and resembling the "lymphatic glands" (compare p. 477) which occur along the lymph-

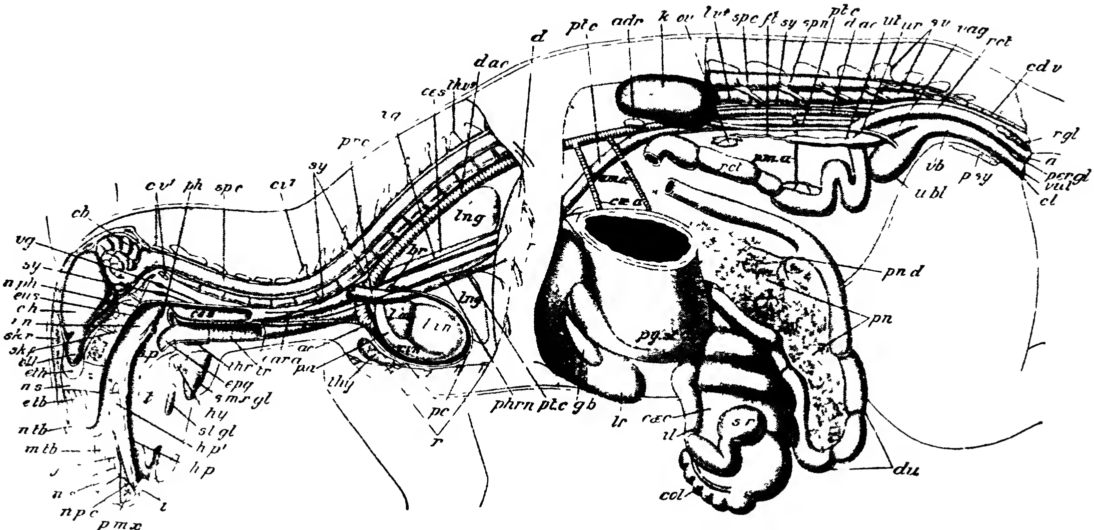


Fig. 149.—Dissection of a female Rabbit from the left side (× ⅓)

The left side of the body-wall, skull, and spinal canal is cut away to the median plane so as to expose the thoracic, pericardial, abdominal and neural cavities, the left half of the liver, the cardiac end of the stomach, and part of the ileum, colon, cæcum, and rectum are removed, the duodenum and proximal end of the cæcum being slightly displaced towards the ventral side (Modified from a drawing by T J P)

a anus, *adr* left adrenal, *a m a* anterior mesenteric artery, *ao* arch of aorta, *br* left bronchus, *cæc* cæcum, *car a* left carotid artery, *cb* cerebellum, *cd v* caudal vertebræ, *c h* cerebral hemisphere, *cl* clitoris, *cœ a* cœliac artery, *col* colon, *c v*[1] atlas, *c v*[7] seventh cervical vertebra, *d* diaphragm, *d ao* dorsal aorta, *du* duodenum, *epg* epiglottis *e tb* ethmo-turbinal, *eth* ethmoid, *eus* aperture

of Eustachian tube, *f t* uterine tube, *g b.* gall-bladder, *h p.* hard palate, *h. p'* bones of hard palate, *hy* hyoid; *i.* incisors; *il* ileum, *i n* passage of internal nostrils; *j* Jacobson's organ, *k.* left kidney, *l au* left auricle, *lng* left lung, seen through pleura, *lr* liver, *l v*[4] fourth lumbar vertebra, *l vn* left ventricle; *m tb* maxillo-turbinal; *n p c* naso palatine canal, *n ph* naso-pharynx; *n tb* naso-turbinal, *n. s* nasal septum (middle part cut away), *œs.* gullet, *ol l* olfactory lobe, *ov* left ovary, *p a* pulmonary artery, *pc* pericardium, *per. gl.* perineal gland, *ph* pharynx, *phr n* phrenic nerve, (origin not shown), *p n a* posterior mesenteric artery, *p mx* premaxilla, *pn* pancreas, *pn d* pancreatic duct, *pr. c* left precaval; *p sy* pelvic symphysis, *pt c* postcaval, *py st.* pyloric region of stomach; *r* ribs, *rct* rectum, *r gl* rectal gland, *r vn* right ventricle; *sk f* floor, and *sk r* roof of skull, *sl gl* sublingual gland, *s mx gl* submaxillary gland, *s p.* soft palate, ending in the velum palati, on the lower side of which a tonsil is seen, *sp c* spinal cord, *sp. n* spinal (lumbar) nerves; *s r* sacculus rotundus of ileum, *s v* first sacral vertebra, *sy* sympathetic (the anterior end shown on the right side, the rest on the left), *t* tongue, *thr* thyroid, *th. v*[9] ninth thoracic vertebra, *thy* thymus; *tr.* trachea; *u bl* urinary bladder, *ur.* ureter; *ut* uterus, *vag* vagina, *vb* vestibule, *vg* vagus (the anterior end shown on the right side, the rest on the left); *vul* vulva.

trunks; it has the form of a small pit with a broad papilla on its outer margin. The *tongue* (*t*) lies on the floor of the mouth to which it is attached below, its anterior, rounded end being free: the surface of its posterior part is elevated, and elsewhere—but more particularly on the tip—its covering of mucous membrane is produced into minute, finger-shaped *papillæ*, on which some of the microscopic organs of taste are situated (compare p. 192). Taste-organs are also present on a pair of *circumvallate papillæ* on the dorsal side of the tongue towards its posterior end, and on a pair of transversely ridged areas—the *foliate papillæ*, situated laterally, slightly anterior to the former. The main substance of the tongue is composed of muscles, some extrinsic, or arising from other parts, and others intrinsic, or entirely confined to the organ in question.

The *teeth* (Figs. 138 and 139), as we have seen, are not all alike, as in the dogfish and frog; there are *incisors* and *cheek-teeth* or grinders, the latter being divisible into two series—the *premolars* and the *molars*. In most Mammals there is also a pair of *canine* teeth situated between the incisors and premolars, and these are especially long and pointed in such carnivorous animals as the dog and cat. In the dogfish and frog, again,

the teeth are continually renewed as they become worn out, but in Mammals there are only two functional sets, which are known respectively as the *deciduous* or "*milk*" *teeth*, and the *successional* or *permanent teeth:* certain of the former may even be absorbed before birth, as is the case with the incisors of the rabbit. The incisors and premolars (and in Mammals in which they are present the canines also) have deciduous predecessors, the molars developing behind the premolars and having no predecessors.

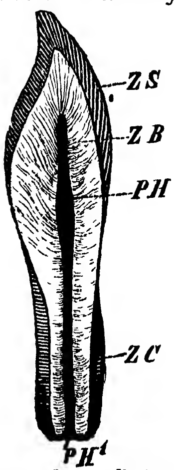


FIG. 150.—Longitudinal section of a mammalian tooth, semi-diagrammatic.
PH pulp-cavity; *PH*[1]. opening of same, *ZB* dentine, *ZC*. cement; *ZS* enamel (From Wiedersheim's *Comp. Anatomy*)

All the teeth are embedded in deep sockets or *alveoli* of the jaw-bones, and each contains a *pulp-cavity* (Fig. 150, *PH*) extending into it from the base and containing blood-vessels and nerves. In the case of the rabbit, the aperture of the pulp-cavity (*PH*[1]) remains wide open in each tooth, and the substance of the tooth is continually added to at its base as it wears away at the other end: in many Mammals, however (*e.g.*, dog, cat, man), the aperture becomes narrowed and growth ceases after a time, the base of the tooth forming one or more *roots* or *fangs*. The main substance of each tooth is formed of *dentine* (*ZB*), into which the pulp-cavity extends for a considerable distance and round which the *enamel* (*ZS*) forms an external layer, which may become more or less folded inwards (as in the cheek-teeth and front upper incisors of the rabbit), the *cement* (*ZC*) extending into the folds (compare p. 473).

The number of the various teeth in the jaws is conveniently expressed by a *dental formula*, in which the kind of tooth (incisor, canine, premolar, or molar) is indicated by the initial letter, *i*, *c*, *pm*, or *m*; and the whole formula has the arrangement of four vulgar fractions, in each of which the numerator indicates the number of teeth in the upper, the denominator that of those in the lower jaw, only those of one side being indicated, since the teeth of the right and left sides are always the same. Thus the dental formula of the rabbit is $i\frac{2}{1}$, $c\frac{0}{0}$, $pm\frac{3}{2}$, $m\frac{3}{3} = 28$.

The anterior incisors in the upper jaw of the rabbit are long and greatly curved. They are surrounded by enamel, which is much thicker on the anterior surface, where it presents a median groove; the posterior upper incisors are much smaller and are situated behind the anterior ones. In the lower jaw the single pair of long and curved incisors have no median groove, and they bite between the anterior and posterior upper incisors: owing to the thick layer of enamel anteriorly, they, like the large upper incisors, wear away less quickly in this region, and thus remain sharp, like a chisel, at their biting edges. The premolars and molars, on the other hand, are modified for grinding the food, to do which satisfactorily it is necessary that they should have broad *crowns* with a surface which wears unevenly. This is effected in most of the cheek-teeth by the enamel becoming involuted along the outer side in a longitudinal direction, so as to form a groove extending into the dentine almost to the other side, the groove becoming filled up with cement. As the enamel is harder than the dentine and cement, it thus gives rise to ridges as the crown wears. The first upper premolar and the last upper and lower molars are simpler than the others, and the first lower premolar has two grooves.

Connected with the mouth-cavity are several pairs of *salivary glands*, not present in the other Vertebrates we have examined, the secretion of which—*saliva*—contains a ferment called *ptyalin*, which is capable of converting starch into sugar (compare p. 78). The food taken into the mouth is ground up or masticated and mixed with

the saliva before passing down the gullet, and thus digestion begins in the mouth.

The *infra-orbital salivary gland* is a large, lobulated pinkish mass situated in the antero-ventral region of the orbit, below and in front of the eyeball. its duct passes downwards to open into the mouth nearly opposite and externally to the second premolar. The *parotid gland* is a soft, irregular, flattened organ, lying close beneath the skin, just below and in front of the base of the external ear; its duct passes forward and opens close to the duct of the infra-orbital gland. The *sub-maxillary gland* (Fig. 149, *s. mx gl*) is a reddish, ovoid, compact body situated inside the angle of the lower jaw and near the middle line, somewhat anterior to the larynx · its duct runs forward to open into the mouth a short distance behind the lower incisors. The *sublingual gland* (*sl gl*) is an elongated structure situated on the inner side of the mandible, and having several ducts opening independently into the mouth.

The oral cavity is continued backwards as the *pharynx* (*ph*): this begins at the velum palati, above which it extends forwards as the *naso-pharynx* (*n. ph*); the latter is continuous with the passage of the internal nostrils, and into it open the Eustachian tubes (*eus*, compare pp. 17 and 47). On the floor of the pharynx, behind the base of the tongue, is the *glottis*, which leads into the larynx and is guarded in front by an elastic, leaf-like, cartilaginous flap, the *epiglottis* (*epg*): this projects upwards towards the velum palati and is capable of being pressed backwards over the glottis during the passage of food from the mouth to the gullet.

The *gullet* (Figs. 149 and 151, *œs*) is a narrow but dilatable tube which passes backwards along the neck and through the thorax, entering the abdomen through an aperture in the diaphragm and then opening into the *stomach* (Figs. 148, M, and 151), a wide, curved sac, elongated transversely and greatly dilated at the *cardiac* end (Fig. 151, *cd. st*), which lies towards the left side of the body: the *pyloric* end (Fig. 151, *py. st*) from which the

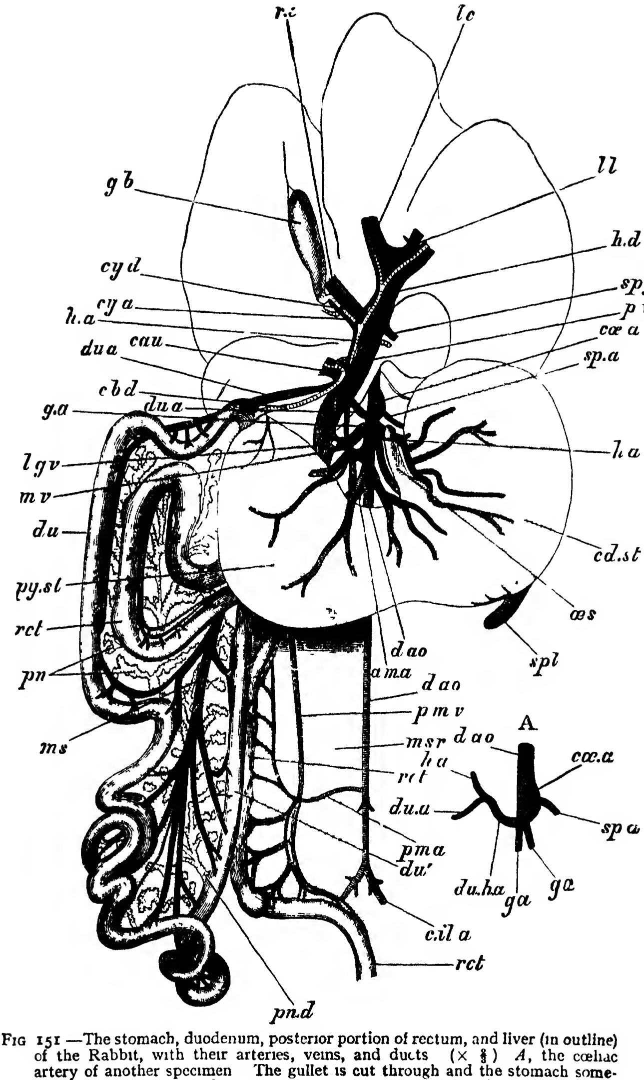


FIG 151 —The stomach, duodenum, posterior portion of rectum, and liver (in outline) of the Rabbit, with their arteries, veins, and ducts (× ⅜) *A*, the cœliac artery of another specimen The gullet is cut through and the stomach somewhat displaced backwards to show the ramifications of the cœliac artery (*cœ a*),

the duodenum is spread out to the right of the subject to show the pancreas (*pn*), the branches of the bile-duct (*c. b. d*), portal vein (*p v*) and hepatic artery (*h a*) are supposed to be traced some distance into the various lobes of the liver.
a m a anterior mesenteric artery, *cau* caudate lobe of liver with its artery, vein, and bile-duct, *c b d* common bile-duct, *cd st.* cardiac portion of stomach, *c il a* common iliac artery, *cœ. a* cœliac artery; *cy a* cystic artery, *cy d* cystic duct, *d ao* dorsal aorta; *du* proximal, and *du'* distal limbs of duodenum, *du a* duodenal artery, *du h. a* (in *A*), duodeno-hepatic artery, *g a* gastric artery and vein, *g b* gall-bladder, *h a* hepatic artery, *h d* left hepatic duct, *l c* left central lobe of liver, with its artery, vein, and bile-duct, *l g. v* lieno-gastric vein, *l l* left lateral lobe of liver, with its artery, vein, and bile-duct, *ms* branch of mesenteric artery and vein to duodenum, *ms r* mesentery of the rectum, *m v* chief mesenteric vein, *œs* gullet, *p m a* posterior mesenteric artery, *p m v.* posterior mesenteric vein, *pn* pancreas, *pn d* pancreatic duct, *p v* portal vein, *py st* pyloric portion of stomach, *rct* rectum, *r c* right central lobe of liver, with artery, vein, and bile-duct, *spg* Spigelian lobe of liver with its artery, vein, and bile-duct, *spl* spleen; *sp. a* splenic artery. (From Parker's *Zootomy*)

duodenum arises, towards the animal's right, is less dilated and has much thicker muscular walls. The mucous membrane of the stomach, in which the microscopic *gastric glands* (p. 139) are contained, is raised into ridges or *rugæ*, and there is a circular *pyloric valve* at the entrance to the intestine.

The *duodenum* (*du*) extends backwards along almost the whole length of the abdomen and then turns forwards again, forming a slightly coiled U-shaped loop, and becoming continuous with the very long and coiled second portion of the small intestine or *ileum* (Fig. 149, *il*), which finally dilates to form a rounded sac (*s. r*) opening into the proximal end of the dark-coloured *colon* (Figs. 148 Q, 149, *col*), or first portion of the large intestine. The colon has a much greater diameter than the small intestine, and presents a series of sacculations arranged in three rows, separated by flat regions of its wall: it passes insensibly into the second portion of the large intestine or *rectum* (*rct*), which is of about the same diameter as the small intestine, and is recognisable by its rounded swellings containing the pill-like fæces: it passes into the pelvic cavity to open by the anus (*a*). At the junction of the ileum and colon is a relatively enormous blind-gut or *cæcum* (Figs. 148, P, 149 *cæc*)—a structure not met with in either the dogfish or the frog, and only reach

ing such a relatively large size as in the rabbit in certain other herbivorous Mammals in which the stomach has a simple form: in those which possess a complicated stomach (viz., Ruminants) the cæcum is comparatively small. It is continuous with the proximal end of the colon, which contains an intra-colic valve and into which the round sac at the distal end of the ileum opens by a circular aperture provided with an *ileo-colic valve*. From this point arises the thin-walled cæcum, which lies coiled on itself amongst the folds of the rest of the intestine: it is about an inch in diameter, and a spiral constriction is seen on the outside marking the attachment, on the inside, of a *spiral valve*—like that of the dogfish's intestine but narrower—which makes about twenty-four turns and ends at the base of a blind, finger-shaped process, the *vermiform appendix*, which forms the apex of the cæcum. The whole canal is supported by a mesentery (p. 22), the right and left halves of which are united, and which has a very complicated arrangement in correspondence with the numerous folds of the intestine.

It will be noticed that the intestine is much more differentiated as regards its subdivisions than in the Vertebrates previously examined, and also that it is relatively much longer, being fifteen or sixteen times as long as the body (compare p. 22)

On cutting open the small intestine, its mucous membrane is seen to be raised into minute, finger-shaped elevations or *villi*, and here and there certain patches present a honeycombed appearance; these portions are known as *Peyer's patches*, and, like the tonsils, thymus, and spleen, consist of masses of lymphoid follicles composed of a connective-tissue framework in which numerous leucocytes are embedded Other so-called "lymphatic glands" or *adenoids* are present in the mesentery and elsewhere. Peyer's patches also occur in the proximal end of the colon, close to the ileo-colic aperture; and the round sac with which the colon communicates, as well as the vermiform appendix, are lined with similar lymphoid tissue. The mucous

membrane of the colon has no villi, but, like that of the spiral valve, is raised into small papillæ ; while that of the rectum is smooth

The *liver* (Figs. 148, L, 149, *lr*, and 151) is a large organ, consisting of five lobes. Its anterior surface is convex and is applied to the diaphragm, its posterior concave surface fitting against the stomach. A median vertical fold of the peritoneum attaches it to the diaphragm, and marks the boundary between the *right* and *left central lobes* (Fig 151, *r.c*, *l c*). Externally to the left central lobe, between it and the cardiac end of the stomach, is the *left lateral lobe* (*l. l*), and externally to the right central lobe the *caudate lobe* (*cau*), applied to the pyloric end of the stomach and hollowed posteriorly, when it fits over the right kidney: a small *Spigelian lobe* (*spg*) fits closely against the concave anterior surface of the stomach. The *bile-duct* is made up of several *hepatic ducts* (*h. d*) from the various lobes of the liver, as well as of a *cystic duct* (*cy. d*) from the pear-shaped *gall-bladder* (*g. b*), which is embedded in the right central lobe of the liver the *common bile-duct* (*c. b. d*) thus formed opens into the dorsal side of the duodenum by a prominent aperture a short distance beyond the pylorus.

The *pancreas* (Figs. 149 and 151, *pn*) is a diffuse gland, consisting of a number of small lobules looking not unlike masses of fat, spread all over the mesentery which connects the two limbs of the duodenum. The small ducts from the various lobules run together to form the main *pancreatic duct* (*pn. d*) which opens, independently of the bile-duct, into the distal limb of the duodenal loop a couple of inches or so beyond the bend.

The *spleen* (Fig. 151, *spl*) is a long, flat body of a dark red colour, attached to the cardiac end of the stomach by a sheet of peritoneum (compare p. 23).

Organs of Respiration and Voice.—Owing to the presence of a neck, the lungs are situated at some distance from the glottis (Fig. 149), and, instead of a short laryngo-tracheal chamber, as in the frog (p. 149), there is a windpipe or *trachea* (*tr*) extending along the neck just ventrally to the gullet, its anterior end forming the *larynx* (Fig. 152) or organ of voice (p. 152), and communicating with the pharynx through the glottis. The cartilaginous rings of the trachea are incomplete dorsally, and the cartilages of the larynx are more highly differentiated than in the frog, apart from the presence of an *epiglottis* (*ep*, see p. 474). The largest and most anterior laryngeal cartilage is the *thyroid* (*th*), which, like the epiglottis, is peculiar to Mammals: it has the form of a broad ring, incomplete dorsally, and is the part of the larynx which can be felt externally. The second cartilage is the *cricoid* (*cr*), represented in the frog by a ring-shaped cartilage at the base of the lungs (p. 149): its form is somewhat like that of a signet ring, being broad dorsally —where it lies mainly between the edges of the thyroid— and narrow ventrally. A pair of *arytenoid* (*ary*) cartilages are articulated to the dorsal and inner surface of the cricoid, and each is produced into a projecting process situated between the two edges of the thyroid cartilage. The *vocal cords* (p. 152) are a pair of elastic folds extending across the cavity of the larynx from the thyroid below to the arytenoids above, each bounded in front by a depression.

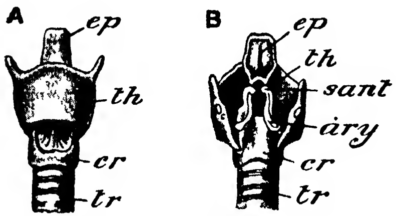


FIG. 152.—Larynx of Rabbit A, ventral view, B, dorsal view.
ary arytenoid, *cr.* cricoid, *ep* epiglottis; *sant* cartilage of Santorini, *th* thyroid, *tr* trachea From Krause, after Schneider)

In the position of rest, the vocal cords lie at an acute angle to one another, as in the frog; they can be brought into parallelism and regulated by the action of a number of intrinsic and extrinsic muscles, and are set in vibration by the respiratory current of air.

After entering the thorax, the trachea divides into two *bronchi* (Fig. 149, *br*), one entering each lung and giving off branches to its different lobes: the bronchi, like the trachea, are supported by incomplete cartilaginous rings at their proximal ends, but these gradually disappear after the bronchi have entered the lungs.

The elastic *lungs* (Figs. 148, G, and 149, *lng*) are not hollow sacs, like those of the frog, but are spongy bodies, of a light pink colour, situated on either side of and above the heart, and filling the greater part of the thoracic cavity, but collapsing as soon as the wall of the thorax is perforated. Each is subdivided into two *main lobes*, and the right lung has in addition two small *accessory lobes*, an anterior and a posterior, the latter lying in the median line, behind the heart, and being closely applied to the gullet

Each pulmonary artery (Figs. 148, E, and 149, *p a*) crosses the main bronchus anteriorly to the point at which it branches into the various lobes, except in the case of the anterior accessory lobe, the bronchus to which comes off in front of the artery and may even arise from the trachea before its bifurcation. Microscopic examination shows that the bronchi divide and subdivide to form a ramifying system of tubes, each ultimate branch of which opens into a minute chamber or *infundibulum*, which in structure closely resembles a frog's lung in miniature.

The parietal layer of the pleura (p. 469) lines the cavity of the thorax, and is reflected over each lung at the entrance of the bronchus to form the visceral layer: in the median line it forms a vertical partition, the *mediastinum*, with which it is continuous on the ventral side of the vertebral column above, and beneath the

pericardium below (Fig. 153). Thus each lung (*l. lng*, *r. lng*) has its own separate *pleural cavity* (*l. pl*, *r. pl*), separated from its fellow by the right and left mediastinum, the space between which is called the *mediastinal space*. The anterior and dorsal parts of this space are narrow, and enclose the posterior part of the trachea and

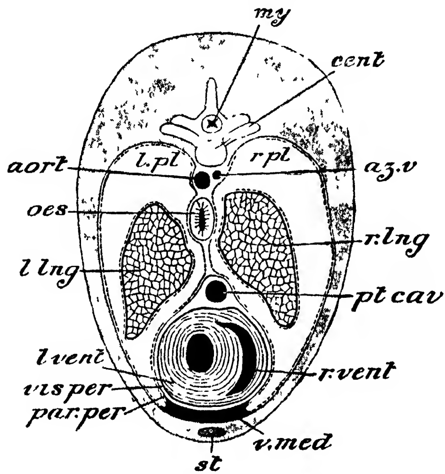


FIG 153 —Diagrammatic transverse section of the Rabbit's thorax in the region of the ventricles, to show the relations of the pleuræ and mediastinum (dotted line), etc The lungs are contracted (× ⅜)
aort dorsal aorta; *az. v.* azygos vein; *cent* centrum of thoracic vertebra; *l lng* left lung; *l pl.* left pleural cavity; *l vent.* left ventricle, *my* spinal cord, *oes* gullet; *par per* parietal layer of pericardium; *pt cav.* postcaval, close to its entrance into right auricle; *r lng* right lung, *r pl* right pleural cavity, *r. vent* right ventricle; *st* sternum, *vis per* visceral layer of pericardium, *v. med* ventral mediastinal space. (From Parker and Haswell's *Zoology*)

the bronchi, as well as the gullet (*œs*) and main blood-vessels (*aort, az. v, pt. cav*); its middle part is wide, and encloses the heart (*l. vent, r. vent*), the mediastinum here fusing with the visceral layer of the pericardium (*vis. per*) and thus obliterating the space; below this it again narrows to form the ventral mediastinal space (*v. med*), in which the thymus (p 469) is situated.

In the entire animal, the air-tight pleural cavities are

completely filled by the lungs, so that the parietal and visceral layers of the pleuræ are practically in contact, there being only a lubricating serous fluid (lymph) between them. The pressure of the air in the bronchial cavities of the lungs is therefore sufficient to keep them distended; but as soon as the pleural cavities are perforated, air passes in and equalises the pressure: the elasticity of the lungs then comes into play, causing them to collapse. When the muscles of the diaphragm contract (p. 469), air is drawn into the lungs, and this process is aided by the external intercostal muscles (p. 467) and, in forced respiration, by other muscles of the body-wall also. The mechanism of respiration may therefore be compared with a suction-pump, while that in the frog resembles a force-pump (p. 151).

On either side of the larynx is a soft, vascular, gland-like *thyroid* body, consisting of two lateral portions connected ventrally by a median bridge Its function is not thoroughly understood: morphologically it represents a gland developed from the pharynx, but it loses its connection with the latter and thus has no duct. The glandular vesicles of which it is composed give rise to an albuminous substance containing iodine, which is passed into the blood and lymph; if extirpated in the living animal, various functional disturbances result. We are also ignorant of the function of the thymus (p. 469), which is largest in young animals, becoming reduced in size in adults

Organs of Circulation.—The *heart*, as in all Vertebrates, is enclosed in a *pericardium* consisting of parietal and visceral layers (Fig. 153), between which is a serous pericardial fluid. There is a complete separation between the arterial and venous blood in the heart, for in addition to an auricular septum, as in the frog (p. 84), the ventricular portion is divided into right and left chambers by a partition (Fig. 153), as in the Birds (p. 436), the arterial blood from the lungs entering the left auricle and thence passing into the left

ventricle to be pumped into the aorta, and the venous blood entering the right auricle and thence into the right ventricle to pass to the lungs through the pulmonary artery. A distinct conus arteriosus and sinus venosus (p. 79) can no longer be recognised, the former having become practically absorbed into the ventricular portion of the heart, and the latter into the right auricle; so that the aorta (together with the carotids) and the pulmonary artery now arise directly from the left and right ventricles respectively, and the precavals and postcaval enter the right auricle directly (Figs. 149, 154, and 155)

The line of separation between the two ventricles can be seen externally as an oblique depression extending from the base of the heart backwards and to the right, but not reaching the apex, which is formed by the left ventricle only. The small, irregular cavity of the latter is enclosed by very thick muscular walls, and is partly surrounded by the right ventricle, the cavity of which is crescentic in transverse section (Fig. 153), while its walls are much thinner than those of the left ventricle as it has only to pump the blood to the lungs. The auricles have thin walls: each is produced into a little flap or *appendix* which envelops the base of the corresponding ventricle, and the walls of which are strengthened by a network of muscular bands.

In the auricular septum is a thin, oval area, the *fossa ovalis* (Fig 154, *f. ov*), which in the embryo is perforated and so allows the blood from the posterior part of the body to pass directly into the left auricle without going to the lungs, which are not, of course, functional until the animal is born.

The two auriculo-ventricular apertures are guarded by valves—that of the left side, or *mitral valve,* consisting of two membranous flaps, that of the right, or *tricuspid valve* (Fig. 154, *tri. v*), of three flaps: the valves

are attached by their bases to the margins of the apertures, their apices extending into the corresponding ventricles. Attached to their edges are tendinous cords arising from conical elevations of the ventricular walls known as *papillary muscles*, which are much larger in the left ventricle than in the right (*m. pap*): these serve to prevent the valves from being pushed into the auricles when the ventricles contract.

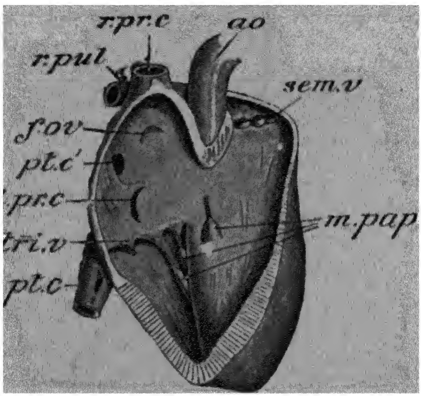


FIG. 154.—Heart of the Rabbit, seen from the right side, the walls of the right auricle and right ventricle partly removed so as to expose the cavities. (× 1½.) *ao* aorta; *f. ov.* fossa ovalis; *l. pr. c.* opening of left precaval; *m. pap* papillary muscles; *pt. c.* postcaval; *pt. c'* opening of postcaval, with Eustachian valve below; *r. pr. c* right precaval; *r. pul* right pulmonary artery; *sem. v* semilunar valves at base of pulmonary artery; *tri. v.* tricuspid valve. (From Parker and Haswell's *Zoology*.)

The right ventricle narrows towards its base, on the ventral side of the heart, to form a conical prolongation from which arises the *pulmonary artery* (Figs. 148, E, and 155, *p. a*), its aperture being guarded by three pocket-like, semilunar valves (Fig. 154, *sem. v*): the aperture of the aorta from the left ventricle is similarly provided with three semilunar valves. The two precavals (*l. pr. c*, *r. pr. c*) and the postcaval (*pt. c*) communicate, as we have seen, directly with the right auricle, the right

precaval opening into it anteriorly, the left precaval posteriorly, the aperture of the postcaval being just anterior to that of the left precaval. The pulmonary veins from each lung unite and open close together into the left auricle.

A membranous fold, the *Eustachian valve*, extends into the right auricle from the circular ridge surrounding the fossa ovalis (*annulus ovalis*) to the apertures of the postcaval and left precaval respectively: in the embryo this helps to conduct the blood through the aperture in the auricular septum (p. 483) and represents the remains of the sinu-auricular valves (p. 95) It, like the "*ductus arteriosus*" (p. 487, and compare Fig 155), affords another example of a vestigial structure

You will remember that in the frog (p. 85) there are two systematic trunks, representing the second arterial arch of the tadpole and fish (p. 424), and uniting above to form the dorsal aorta. In the Mammal, one of these —the right—disappears in the course of development and all the blood from the left ventricle passes into the single *left aortic arch* (Figs. 154 and 155) from the base of which both carotid arteries arise, the aortic arch then curving over the left bronchus to pass into the dorsal aorta (*d. ao*).

Close to the origin of the aortic arch, just beyond its semilunar valves, two small *coronary arteries* are given off to the walls of the heart; and more anteriorly, at the curve of the arch, arise the vessels which supply the head and fore-limb. There is a certain amount of variation as to the origin of these, which is asymmetrical, and is usually as follows. Springing from the arch of the aorta towards the right side is an *innominate artery* (Fig. 155, *in*), which gives off close to its origin the *left common carotid* (*l. c. c*), and then, passing forwards, divides into the *right common carotid* (*r. c. c*) and the right *subclavian* (*s. cl. a*), the *left subclavian* (*br*) taking its

origin independently from the left side of the arch. Each common carotid passes forwards along the neck, close to the trachea, and at about the level of the larynx divides into an *internal carotid* (*i. c*), which supplies the brain, and an *external carotid* (*e. c*), which goes to the head and face. Each subclavian forms several branches, the most important of which are a *brachial* (*br*) to the fore-limb, a *vertebral* (*vr*) which passes through the vertebrarterial canal of the cervical vertebræ (p. 456) and supplies the spinal cord and brain, and an *anterior epigastric* or *internal mammary* (*a. epg*) running along the inner side of the ventral wall of the thorax The aorta gives off, in the thorax, a series of small paired *intercostal arteries* (*i. cs*) to the body-walls, and then passes into the abdomen, between the pillars of the diaphragm.

A short distance behind the diaphragm the *cœliac artery* (Figs. 151 and 155, *cœ*) arises, and supplies the liver, stomach, and spleen; and about half or three-quarters of an inch further back is the *anterior mesenteric artery* (*a. m. a*), the branches of which pass to the small intestine, pancreas, cæcum, and colon. Close behind the anterior mesenteric is the right—and rather further back the left—*renal artery* (Fig. 155, *r*), and still more posteriorly, a *posterior mesenteric* (*p. m*) to the rectum, and a pair of *spermatic* or *ovarian* arteries (*spm*) to the spermaries or ovaries, as the case may be. A small *caudal artery* (*m. sc*), corresponding to the caudal continuation of the aorta, arises from the dorsal surface of the posterior part of the latter just in front of a pair of large *common iliac arteries* (*c. il. a*), which appear like a bifurcation of the aorta. These are continued outwards and backwards towards the hind-limbs, each giving off an *ilio-lumbar artery* (*i. l*) to the dorsal body-wall and then dividing into an *internal iliac* (*i. il. a*) passing along the dorsal side of the pelvic cavity, and an

external iliac (*e. il. a*) which gives off an artery to the bladder (*s. vs*), and in the female one to the part of the oviduct known as the uterus (*ut*); and then, passing beneath Poupart's ligament (p. 467) to the hind-limb, becomes the *femoral artery* (*fm. a*), from the proximal end of which a *posterior epigastric* (*p. epg*) runs forwards in the ventral abdominal wall. Small *lumbar arteries* are also given off from the aorta to the walls of the abdomen.

The *pulmonary artery* (*p. a*) divides soon after its origin from the right ventricle into two branches, one supplying each lung. Just before its bifurcation it is connected by a short cord, known as the *ductus arteriosus*, with the aorta: this is the solid vestige of the embryonic connection between the fourth arterial arch and the aorta (compare p. 485, and Fig. 155).

Each *precaval* (*l. pr. c, r. pr. c*) receives—a *subclavian* (*s. cl. v*) from the fore-limb, an *external jugular* (*e. ju*) from the head, running along the neck just beneath the skin; a small *anterior epigastric* from the ventral thoracic wall, as well as small vessels from some of the anterior intercostal spaces (*i. cs*) and the anterior surface of the diaphragm (*a. ph*); and a small *internal jugular* (*i. ju*) from the brain, opening into the corresponding external jugular nearly opposite the subclavian. An *azygos vein* (*az. v*), representing part of the right cardinal of the embryo (compare p. 423) and receiving blood from the posterior intercostal spaces, also opens into the base of the right precaval.

There is no renal portal system, as in the dogfish and frog (pp. 423 and 90). A pair of *internal iliac veins* (*i. il. v*) in the pelvic cavity unite to join a median vessel (*c. il. v*), the hinder end of the postcaval, which receives on either side an *external iliac* (*e. il. v*): this is constituted by a *femoral vein* (*fm. v*) from the hind-limb; a *posterior*

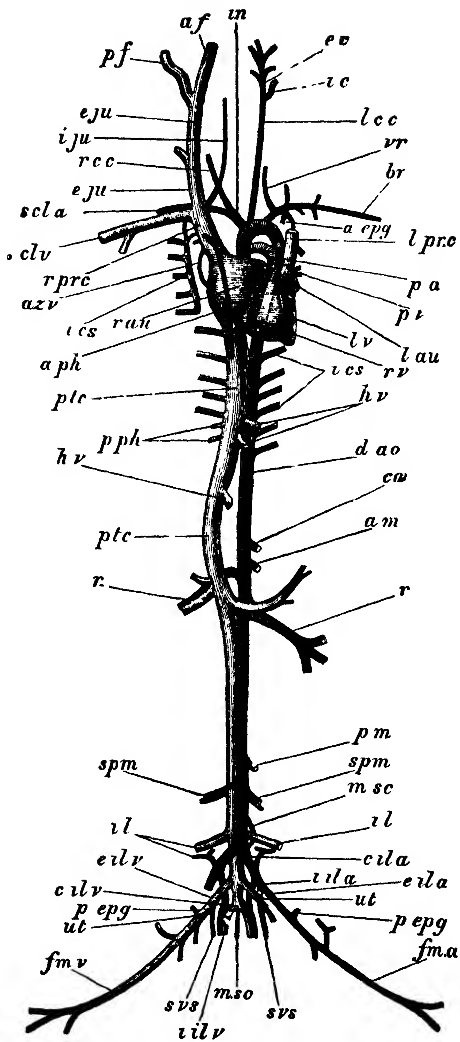


FIG. 155.—The vascular system of the Rabbit from the ventral side. The heart is somewhat displaced towards the left of the subject; the arteries of the right and the veins of the left side are in great measure removed. (× ½.)

a epg anterior epigastric artery; *a. f.* anterior facial vein; *a. m.* anterior mesenteric artery; *a ph.* anterior phrenic vein, *az v* azygos vein; *br* right brachial artery; *c. il. a.* common iliac artery; *c. il v* hinder end of postcaval; *cœ* cœliac artery; *d. ao.* dorsal aorta; *e. c.* external carotid artery; *e il a* external iliac artery, *e il v.* external iliac vein, *e ju* external jugular vein, *fm a* femoral artery, *fm v* femoral vein; *h. v.* hepatic veins; *i. c.* internal carotid artery; *i. cs.* intercostal vessels; *i. ju* internal jugular vein; *i. l.* ilio-lumbar artery and vein, *in* innominate artery; *l. au.* left auricle; *l. c. c.* left common carotid artery, *l pr. c* left precaval vein, *l. v.* left ventricle; *m sc* caudal artery; *p a* pulmonary artery; *p. epg.* posterior epigastric artery and vein, *p. f.* posterior facial vein; *p. m* posterior mesenteric artery, *p ph.* posterior phrenic veins, *ptc* postcaval vein, *p. v* pulmonary vein; *r* renal artery and vein, *r au* right auricle; *r. c. c* right common carotid artery; *r prc.* right precaval vein, *r v.* right ventricle, *scl. a* right subclavian artery; *scl v* right subclavian vein, *spm* spermatic artery and vein; *s. vs.* vesical artery and vein, *ut* uterine artery and vein; *vr.* vertebral artery. (From Parker's *Zootomy*)

epigastric (*p. epg*), from the ventral walls of the abdomen, entering the femoral just external to Poupart's ligament; and by small veins from the bladder as well as from the uterus in the female. Slightly in front of the external iliacs the postcaval receives a pair of large *ilio-lumbar veins* (*i. l*) from the body-walls: the left ilio-lumbar sometimes runs forwards to open into the corresponding renal vein. Rather more anteriorly still are a pair of *spermatic* (*spm*) or *ovarian* veins, and a large *renal vein* (*r*) enters the postcaval from each kidney. As the postcaval passes through the dorsal border of the liver, it receives several large *hepatic veins* (Figs. 151 and 155, *h. v*) from the lobes of that organ. Other small veins from the body-walls and from the posterior surface of the diaphragm also open into the postcaval, which then passes through the central tendon of the diaphragm and runs forward in the mediastinal space (Fig. 153, *pt. cav*) to open into the right auricle.

The *hepatic portal vein* (Fig. 151, *p. v*) is a large vessel situated in the mesentery, ventral to the postcaval. Anteriorly it passes into and divides up in the liver, sending a branch to each lobe: posteriorly it is constituted by a large *anterior mesenteric vein* (*m. v*) returning the blood from the small intestine, colon, and cæcum, and by smaller veins from the stomach, spleen, and duodenum,

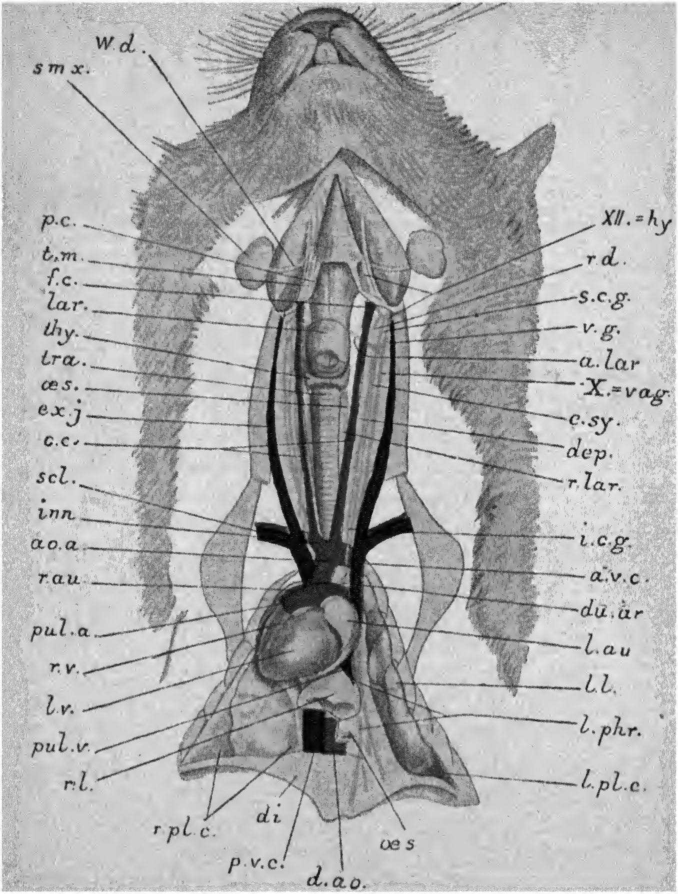


FIG 156 —Dissection of the neck and thorax of the Rabbit The heart has been displaced a little to the right, and the pericardium removed Arteries are coloured red, veins blue, and nerves yellow.

a lar anterior laryngeal branch of the vagus ; ***ao. a*** aortic arch ; ***a v c*** anterior vena cava , ***c c*** common carotid arteries , ***c sy*** cervical sympathetic nerve ; ***d ao*** dorsal aorta , ***dep*** depressor nerve , ***di*** diaphragm , ***du ar*** ductus arteriosus ; ***ex j*** external jugular vein ; ***f c*** point at which the common carotid divides ; ***hy*** hypoglossal nerve , ***i c. g*** inferior or posterior cervical sympathetic ganglion ; ***inn*** innominate artery , ***l au.*** left auricle , ***l l*** left lung ; ***l phr*** left phrenic nerve , ***l pl c*** left pleural cavity , ***l v*** left ventricle , ***lar*** larynx , ***oes*** œsophagus in neck , ***oes'*** the same in the thorax , ***p c*** posterior cornu of the hyoid ; ***p lar.***

posterior laryngeal branch of the vagus, *pul a* pulmonary artery; *pul v* pulmonary vein; *p v c* posterior vena cava, *r. au* right auricle; *r. d* ramus descendens; *r l.* right lung, one part bulging into the mediastinum; *r lar.* recurrent laryngeal nerve; *r pl c.* right pleural cavity; *r v* right ventricle; *s. c g* superior or anterior cervical sympathetic ganglion; *scl* subclavian artery and vein, *smx.* submaxillary gland; *t m.* tendon of mandibular muscle; *thy.* thyroid gland, *tra.* trachea; *v. g.* vagus ganglion, *vag* vagus nerve, *w. d.* duct of submaxillary gland (Wharton's duct); X, XII, cranial nerves (After Borradaille, modified)

as well as by a *posterior mesenteric vein* (*p. m. v*) from the rectum.

The *pulmonary veins* have already been described (p. 485) In the freshly-killed animal a number of the delicate, transparent *lymphatic vessels* (p. 103) can be made out, those from the intestine (*lacteals*) running in the mesentery. They come into connection with numerous adenoids (p. 469) in the mesentery and elsewhere, and most of them communicate with a main trunk—the *thoracic duct*—which extends from the abdomen through the thorax on the left and upper side of the aorta. The thoracic duct also receives the lymphatics from the left side of the head and neck and the fore-limb, and opens into the veins at the junction of the left external jugular and subclavian: the lymphatics of the right side of the head and neck and right fore-limb communicate with the corresponding veins of the right side.

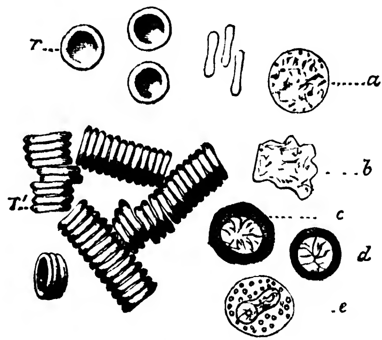


FIG 157—Blood-corpuscles of Man *r.* red corpuscles seen on the flat, *r'* red corpuscles seen on edge, and run together in rows; *a b.* white corpuscles showing amœboid movement, nucleus not seen, *c. d e* white corpuscles showing nuclei, *e* containing also granules. (From Foster and Shore's *Physiology*)

Blood.—The blood of the rabbit differs from that of the frog in certain respects. The red blood-corpuscles are circular, biconcave, non-nucleated discs, instead of being oval, biconvex, and nucleated as in the other classes of vertebrates; and the white corpuscles are

slightly larger than the red corpuscles. The temperature of the blood, instead of varying with that of the surrounding air, is almost constant at about 100° F. This is what is meant when we say that the rabbit is a warm-blooded animal.

Nervous System.—The **brain** (Figs. 149, 158, and 159) reaches a much higher development than in the other Vertebrates we have already studied. The prosencephalon is subdivided into two *cerebral hemispheres* (*ch*), of much larger relative size than those of the frog (Fig. 158) and forming about two-thirds of the whole brain. They are closely applied to one another along their flat internal surfaces, are roughly conical in form, narrower in front (*frontal lobes*), broadening out posteriorly (*parietal lobes*)—where they overlap the diencephalon and optic lobes and abut against the cerebellum, and produced downwards into the prominent *temporal lobes* which partly overlap the crura cerebri below. Their external layer or *cortex* is formed of grey matter, and their surface is convex and smooth, except for the presence of slight lateral grooves between the lobes: in many Mammals the hemispheres are highly convoluted, *i.e.*, raised into numerous winding elevations or *gyri*, separated by narrow grooves or *sulci*. A broad transverse band of nerve-fibres forms a commissure connecting the two hemispheres known as the *corpus callosum* (Figs. 158 and 159, *cp. cl*): this structure is confined to the Mammalia, and is even wanting in certain of the lower members of the class. The *olfactory lobes* (*olf*) are club-shaped, and extend backwards along the ventral surface of the hemispheres in the form of narrow bands as far as the temporal lobes.

The *diencephalon* consists of a right and a left *optic thalamus* (*o. th*) between which is the slit-like *third ventricle* (v^3) roofed over by a thin membrane continuous

with a vascular *choroid plexus* (Fig 71, *vl ip*), anc m
its hinder part arises a stalk bearing at the end a s
rounded *pineal body* (*pn*). The floor of the diencepha

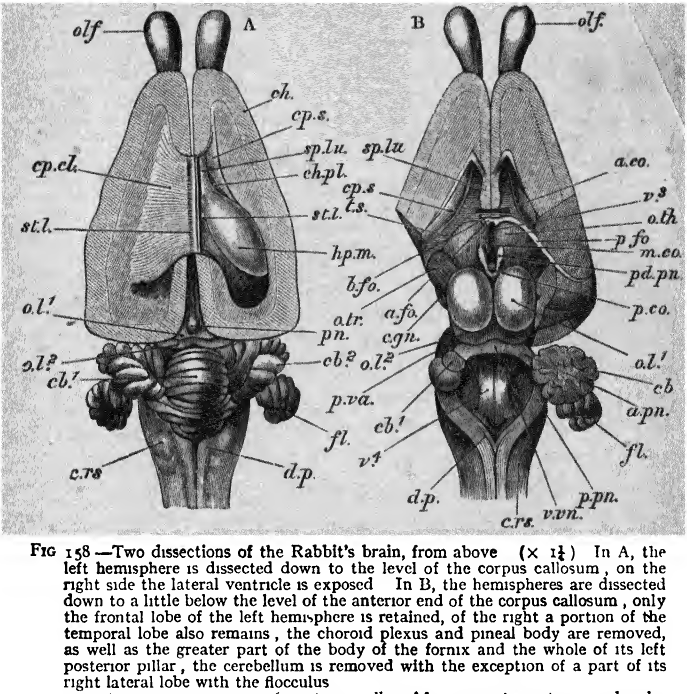


FIG 158 —Two dissections of the Rabbit's brain, from above (× 1½) In A, the left hemisphere is dissected down to the level of the corpus callosum, on the right side the lateral ventricle is exposed In B, the hemispheres are dissected down to a little below the level of the anterior end of the corpus callosum, only the frontal lobe of the left hemisphere is retained, of the right a portion of the temporal lobe also remains, the choroid plexus and pineal body are removed, as well as the greater part of the body of the fornix and the whole of its left posterior pillar, the cerebellum is removed with the exception of a part of its right lateral lobe with the flocculus

a co anterior commissure, *a fo* anterior pillar of fornix, *a pn* anterior peduncles of cerebellum, *b fo* body of fornix, cb^1 central lobe of cerebellum, cb^2 its lateral lobe, *c gn* elevation on the optic thalamus, *c h* cerebral hemisphere, *ch pl* part of choroid plexus; *cp cl* corpus callosum, *cp s* corpus striatum, *c rs* and *d p* elevations on the bulb, *fl.* flocculus, *hp m* hippocampus, *m co* middle commissure, $o.\ l^1$, $o\ l^2$, optic lobes, *olf* olfactory lobe, *o th* optic thalamus; *o tr* optic tract (continuation of chiasma), *p co* posterior commissure, *p fo* posterior pillar of fornix, *pn* pineal body, *pd pn* its peduncle; *p pn* posterior peduncles of cerebellum, *p va* fibres of pons Varolii forming middle peduncles of cerebellum, *sp lu* septum lucidum, *st l* line on corpus callosum, *t s* band of white matter lying beneath choroid plexus, *v vn* valve of Vieussens; v^3 third ventricle; v^4. fourth ventricle. (From Parker's *Zootomy*)

is produced downwards to form the *infundibulum* (*inf*), to which the *pituitary body* (*pty*) is attached. In front of

the ...ndibulum is the *optic chiasma* (*o. ch*), and behind it ...all, rounded lobe (*c. ma*).

...h *optic lobe* is divided into two by a transverse ...ow, so that there are four rounded elevations in this ...ion—an anterior, larger pair (*o.* l^1), and a posterior, ...naller pair (*o.* l^2). Below the optic lobes are the ...*rura cerebri* (*c. c*)—two strong, diverging bands passing forwards and outwards from the bulb to the hemispheres.

The *bulb* or *medulla oblongata* (*m o*) is slightly flattened dorso-ventrally, and passes behind into the spinal cord, the dorsal and ventral fissures of which are continued into it: the *fourth ventricle* (v^4) which it contains is roofed over by the thin pia mater only (p. 163). Ventrally its anterior border is marked by a stout band of nerve-fibres running transversely, and known as the *pons Varolii* (*p. va*). The large *cerebellum* is connected with the dorsal surface of the brain by three pairs of peduncles (Fig. 158, *a. pn, p. va, p. pn*), and consists of a median *central lobe* (cb^1) and of two *lateral lobes* (cb^2), on the outer side of each of which is a smaller *floccular lobe* (*fl*). The grey matter is superficial, and the surface is marked by numerous folds which in section present a tree-like pattern (*arbor vitæ*), brought about by the arrangement of the grey and white matter (Fig. 159).

The fourth ventricle is not prolonged into the cerebellum to any extent: it is continued forwards as the *iter*, from which no optic ventricles are given off (compare pp. 165 and 438) and which passes into the narrow but deep *third ventricle* in front (Fig. 159): this is bounded anteriorly by a thin wall, the *lamina terminalis* (*l. t*), and extends into the infundibulum below. At its anterior end are the *foramina of Monro* (*f m*), leading into the middle of the *lateral ventricles* in the hemispheres (Fig. 159). In this region each lateral ventricle is broad

from side to side, but narrow from above downwards; it extends forwards into the frontal lobe, backwards into the parietal lobe, and downwards into the temporal lobe. The olfactory lobes are solid.

A prominent, convex ridge of white matter—the *hippocampus* (Fig. 158, *hp. m*)—projects into the inner side and floor of each lateral ventricle where it descends into the temporal lobe, and closely applied to it is a continuation of

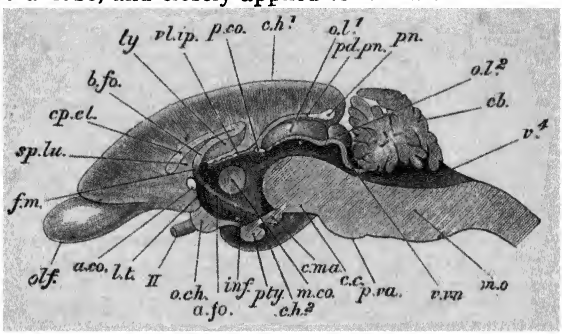


FIG. 159.—Longitudinal vertical section of the Rabbit's brain ($\times 1\frac{1}{4}$) Letters as in preceding figure; in addition—*cb* central lobe of cerebellum, showing arbor vitæ, *c c* crus cerebri, *c. h*¹. parietal, and *cp h*². temporal lobe of cerebral hemisphere, *c ma* elevation behind the infundibulum, *f m* foramen of Monro, *inf* infundibulum, *l t* lamina terminalis, *ly* part of hippocampus, *m o* medulla oblongata, *o ch* optic chiasma, *pty* pituitary body, *vl ip* choroid plexus; *v vn* valve of Vieussens, *II* optic nerve. (From Parker's *Zootomy*)

the choroid plexus (*ch. pl*), which passes from the roof of the third ventricle into the lateral ventricle through the foramen of Monro. In front of the hippocampus the outer side and floor of the anterior part of the lateral ventricle are thickened to form an eminence of grey matter, the *corpus striatum* (*cp s*). Just beneath the corpus callosum the internal wall of each lateral ventricle is thin, and is known as the *septum lucidum* (*sp lu*); and below it and above the foramina of Monro is another commissure known as the body of the *fornix* (Figs 158 and 159, *b. fo*) which is continuous on either side with two bands—one (posterior pillar) lying along the anterior edge of the hippocampus, and the other (anterior pillar) passing backwards in the side walls of the third ventricle. Connecting the two optic thalami are three transverse bands of nerve-fibres, known respectively as the

anterior (*a co*), *middle* (*m. co*), and *posterior* (*p co*) *commissures*: the middle commissure, which is much the largest, is not represented in the lower Vertebrata

The **spinal cord** (Fig 149, *sp c*) is similar in structure to that already described in other Vertebrates (p. 163). It extends through the entire neural canal, ends in a *filum terminale*, and is swollen opposite the fore- and hind-limbs, where the nerves arise which form the limb-plexuses (p. 169)

The dorsal and ventral roots of the **spinal nerves** lie in the same transverse plane, as in the frog (p. 168), but are relatively shorter than in that animal; after uniting to form the nerve-trunks, they pass directly outwards through the intervertebral foramina. The *brachial plexus* is formed from the four posterior cervical and the first thoracic nerves, and gives off a number of nerves to the shoulder and fore-limb. The *sciatic* or *lumbosacral* plexus is constituted by the two or three hindermost lumbar and the first two or three sacral nerves, and gives off branches to the pelvic region and hind-limb, a *femoral* and a *peroneal* going to the extensor muscles, and a large *sciatic* and an *obturator* (which passes through the obturator foramen, p. 464) supplying the flexor muscles. Arising from the fourth cervical spinal nerve of either side is a *phrenic nerve* (Figs. 149, 156 *l phr*, *phr. n*), which passes backwards, between the heart and the lung of its own side, to supply the muscles of the diaphragm; and a large *auricular nerve*, arising from the third cervical nerve, supplies the external ear.

The origin and distribution of the first ten pairs of **cerebral nerves** correspond in their main features with those seen in the frog (p. 172). The olfactory nerves arise as a number of fine threads and pass through the numerous openings of the cribriform plate at the front end of the cranium. The facial is almost entirely a motor nerve and is chiefly important in supplying the facial muscles, which are very highly developed in Mammals. The vagus (Fig. 156) runs backwards outside the carotid artery and gives off an *anterior laryngeal* branch to the larynx (*a. l*), a *depressor* branch (*dep*) which arises near

the anterior laryngeal, and passes backwards just external to the carotid artery, and a *posterior* or *recurrent laryngeal* branch (*r. lar*) which loops round an artery and runs forwards beside the trachea. After giving off these branches, the vagus passes backwards along the œsophagus and gives the usual branches in the thorax where it can be readily seen lying dorsal to the heart and the root of the lung.

In addition to the ten cerebral nerves enumerated in the frog (p 172) and dogfish, two others—the *spinal accessory* and the *hypoglossal* (represented in the frog by fibres in connection with the vagus and by the first spinal nerve respectively, p. 169)—emerge from the skull and are therefore counted as the eleventh and twelfth cerebral nerves. The former arises from the side of the spinal cord and bulb by numerous fibres, the posterior of which are opposite the fifth spinal nerve, from which point it runs forwards between the dorsal and ventral roots and leaves the skull together with the glosso-pharyngeal and vagus (p. 453), supplying certain muscles of the neck and shoulder. The hypoglossal arises by a number of fibres from the ventral surface of the bulb, passes out through the condylar foramen, curving forwards round the angle of the jaw to supply the muscles of the tongue, and sending a branch backwards, known as the *ramus descendens* (Fig. 156, *r. d*) which goes to certain muscles of the neck.

The relations of the **sympathetic nerves** (Fig. 149, *sy*) are also essentially similar to those occurring in the frog (p. 171). Each passes backwards along the neck (Fig. 156, *c. sy.*) close to the vagus (*vg*) and alongside the carotid artery, enlarging to form an anterior and a posterior cervical ganglion (*s. c. g, i. e. g*) In the thorax it runs just beneath the heads of the ribs, having a ganglion in each intercostal space: it then passes into the abdomen,

lying close to the centra of the vertebræ and having ganglia at intervals. From all the sympathetic ganglia branches are given off connecting them with the spinal nerves (*rami communicantes*), others going to the blood vessels: others again, in the thorax and abdomen, are connected with plexuses from which nerves pass to the heart and abdominal viscera.

In the thorax two large *splanchnic nerves* run off from the cords and, piercing the diaphragm, fuse with a large *cœliac ganglion*, placed in the mesentery just in front of the origin of the anterior mesenteric artery, and united with an anterior *mesenteric ganglion* just behind it From these ganglia numerous branches run off to the abdominal viscera These ganglia and nerves are together spoken of as the *cœliac plexus*.

Sensory Organs.—The sense of touch is situated in microscopic *tactile organs* in the skin, and groups of cells called *taste-buds*, are present on the papillæ of the tongue (p. 471) and on the soft palate (compare pp. 191 and 192).

The *organs of smell* are situated in the olfactory capsules, the form of which has already been described (p. 450). They open externally by the *external nostrils* and are produced backwards above the palate into the passage of the *internal nostrils*, which communicate with the naso-pharynx (Fig. 149, *i. n*, *n. ph*, and see p. 474). The olfactory epithelium, supplied by the olfactory nerves, is situated on the ethmo-turbinal (*e. tb*): the mucous membrane of the maxillo-turbinal (*m. tb*) probably serves merely to warm the inspired air.

On the ventral side of the nasal septum is a pair of small tubular structures known as the *vomero-nasal* or *Jacobson's organs* (Fig. 149, *j*), lined by epithelium and enclosed in cartilages situated just to the inner side of the palatine processes of the premaxillæ (p. 452). Each of them opens anteriorly into the corresponding naso-palatine canal (p. 469) and receives a special branch of the olfactory nerve. The function of these organs is not understood.

The structure of the *eye* (Fig. 160) is similar to that already described in other Vertebrates (p. 193) except that the sclerotic is not cartilaginous, but is composed of dense fibrous tissue, and the lens is relatively smaller than in the dogfish and frog and is markedly biconvex in form, the outer surface being rather flatter

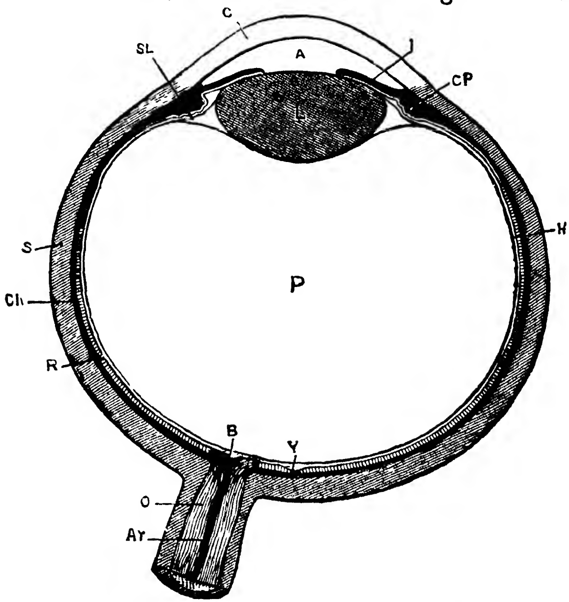


FIG 160 —A diagrammatic transverse section through the Human Eye *A* anterior chamber, *Ar* central artery of the retina, *B* blind spot, *C* cornea, *Ch* choroid, *CP.* ciliary process; *H* hyaloid membrane enclosing the vitreous humour, *I* iris, *L* lens, *O* optic nerve, *P* posterior chamber, *R* retina, *S* sclerotic; *SL* suspensory ligament, *Y.* yellow spot (There is no yellow spot in the eye of rabbit)

than the inner it is capable of adjustment by means of the *ciliary muscle.* This is a continuous ring of delicate muscle consisting of fine unstriped fibres arising from the junction of the sclerotic and cornea and passing backwards into the *ciliary processes.* These are a series of

folds or plaits arranged in a radiating manner all round, into which the choroid is thrown just externally to the iris (compare p. 195).

When the ciliary muscle contracts, it pulls the ciliary processes with the loosely attached choroid forwards towards the origin of the muscle. The ciliary processes carry the attachment of the suspensory ligament with them nearer to the lens, the whole suspensory ligament being thus slackened. In looking at a near object the ciliary muscle contracts, and so slackens the suspensory ligament, and the lens, the pressure on its anterior surface being lessened, becomes by its own elasticity more convex. This power of adjustment for objects at varying distances from the eye is called accommodation.

The eyelids have already been described (p. 444). The four *recti muscles* ensheath the optic nerve, as in the frog (p. 198), but the *superior oblique*, instead of arising—like the *inferior oblique*—in the anterior part of the orbit, takes its origin further back, near the recti, passes forwards through a fibro-cartilaginous pulley at the anterior angle of the orbit, and then backwards and outwards to its insertion on the eyeball.

Between the wall of the orbit and the eyeball are two glands, the secretion of which, passing through ducts perforating the conjunctiva lining the eyelids, serves to keep the outer surface of the eye moist, and is then conducted into the nasal chambers by means of the naso-lacrymal duct (pp. 198 and 451). These two glands correspond to special differentiations of a primarily continuous structure: one, the *Harderian gland*—already met with in the frog—is situated in the antero-ventral region of the orbit: the other, or *lacrymal gland* proper, in its postero-dorsal region. Besides these, a series of small *Meibomian glands* is present on the inner side of the edges of the eyelids, and produces a fatty secretion.

The essential part of the *auditory organ* consists, as in other Vertebrates, of the *membranous labyrinth* with its three *semicircular canals* (p. 198) enclosed in the auditory capsule (periotic bone, p. 449), and consti-

tuting the *internal ear.* The small outgrowth of the sacculus seen in the frog, and known as the *cochlea* (Fig. 65, *cc*), is represented by a relatively larger structure, coiled on itself in a spiral manner, and specially important as regards the sense of hearing The part of the periotic bone which directly surrounds the cavity in which the membranous labyrinth lies is especially hard, and when the outer portion of the bone is cut away, is seen to form a sort of cast of the enclosed organ, the form of which it repeats: this is known as the *bony labyrinth* (Fig. 161). Internally it is separated from the membranous labyrinth by a narrow space all round, containing the perilymph (p. 201) and only shut off from the tympanic cavity at the fenestra ovalis and fenestra rotunda (p. 450) by the membrane which closes each of them.

The membranous cochlea does not run up the middle of the spiral of the bony cochlea, but is attached between its outer wall and a spiral shelf arising from its inner wall Thus the entire cochlea shows three cavities in transverse section —a middle, the membranous cochlea or *scala media*, and a *scala vestibuli* and a *scala tympani* on either side of it respectively, which communicate with one another at the apex of the cochlea and with the perilymphatic cavity surrounding the rest of the membranous labyrinth at its base, where the scala tympani abuts against the membrane of the fenestra rotunda, and the scala vestibuli against that of the fenestra ovalis. On the wall of the scala media which separates it from the scala tympani is a specially modified series of auditory cells forming what is known as the *organ of Corti*, which receives nerve-fibres from a branch of the auditory nerve extending along the spiral shelf of the cochlea.

The *middle ear* is constituted by the tympanic cavity in the tympanic bulla, and communicates with the pharynx by the Eustachian tube (Fig. 161, E). The *tympanic membrane* (M), situated obliquely at the boundary of the bulbous and the tubular portions of the tympanic bone, separates the middle ear from the *external*

ear, consisting of the auditory passage (Ex) and the pinna (p. 444).

The fenestra ovalis is plugged by a small stirrup-shaped bone, the *stapes* (Fig. 161, O_1), one of the three auditory ossicles (p. 450) connecting the internal ear with the tympanic membrane, and probably corresponding morphologically to part or the whole of the frog's

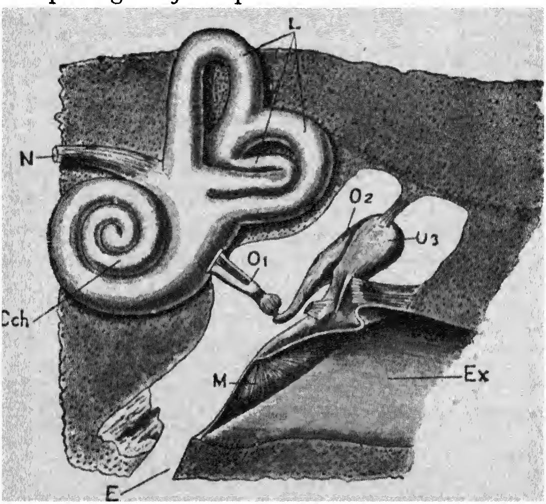


FIG 161.—Diagram of the mammalian bony labyrinth, tympanic cavity, and external auditory passage

Cch bony cochlea; *E* Eustachian tube, *Ex* external auditory passage, *L* bony semicircular canals; *M* tympanic membrane, *N* auditory nerve, O_1 stapes, O_2 incus; O_3 malleus (After Headley)

columella (Fig. 12): with it is connected a small *stapedius muscle*, serving to keep the membrane of the fenestra ovalis on the stretch. The middle bone of the chain is the *incus* (Fig. 161, O_2), a short process of which is articulated to the stapes by the intermediation of a small bony nodule, while its body articulates with the outer bone of the series, the *malleus* (O_3). Arising from the body of the malleus is a handle-like process or

manubrium, which is attached to the tympanic membrane (M): this has the form of the roof of a tent, and is kept on the stretch by a small muscle, the *tensor tympani*, arising from the wall of the tympanic cavity and inserted into the manubrium of the malleus.

The study of development indicates that the malleus corresponds to the ossified articular part of the mandibular cartilage of lower Vertebrates, and the incus to the quadrate (pp 46 and 419): the articulation of the bony mandible with the squamosal in Mammals has rendered these parts unnecessary for their original purpose; and they have undergone a *change of function*, forming an accessory part of the auditory apparatus.

Urinogenital Organs.—The *kidneys* (Fig. 162, *k*) are of a somewhat compressed, oval shape, with a notch or *hilus* on the inner side. They are in close contact with the dorsal wall of the abdominal cavity, the right being somewhat in advance of the left. Towards the hilus, the tubules of which the kidney is composed (p. 154) converge to open into a wide chamber or *pelvis*, which forms the dilated commencement of the ureter. When the kidney is cut across, its substance is seen to be divided into a central mass or *medulla* and a peripheral portion or *cortex*. The former appears radially striated, owing to the tubules in this region being straight and converging to open on the surface of a conical process or *pyramid*, which projects into the pelvis: the cortex contains the coiled portions of the tubules and the Malpighian bodies, and thus has a dotted appearance. The *ureter* (Figs. 162 and 163, *ur*) runs backwards along the dorsal wall of the abdomen to open into the *urinary bladder* (*u. bl*, *b*), a pyriform sac with elastic walls which vary in thickness according as the organ is dilated or contracted. Near the front end of each kidney towards its inner side is a small yellowish *adrenal* body (Fig. 162, *ad*).

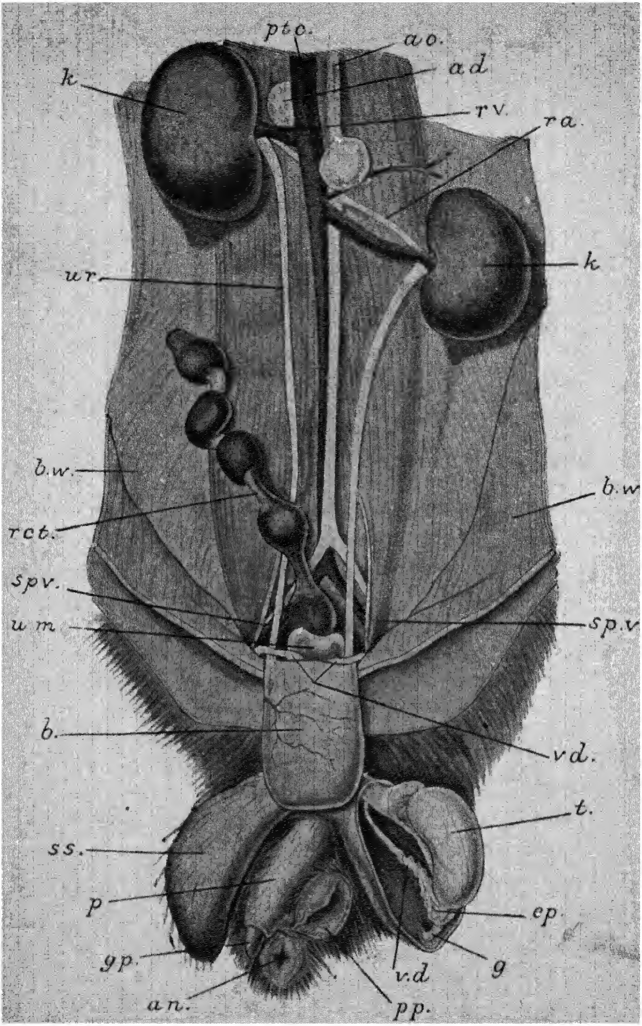


Fig 162.—Dissection of a male Rabbit to show the urinogenital organs *ad* adrenal bodies, *an* anus, *ao* aorta, *b* urinary bladder, *ep* epididymis, *g* gubernaculum testis, *g p* glans penis *k* kidneys, *p* penis, *pp* perineal pouch, *ptc* postcaval vein, *r a* renal arteries; *rct* rectum, *r v* renal veins, *sp v* spermatic artery and vein, *ss* scrotal sac, *t* testis, *u m* uterus masculinus, *ur* ureters, *v d* vas deferens, *v d′* vasa deferentia looping round the ureters (After Roseler and Lamprecht.)

In the male rabbit the *spermaries* are oval bodies which in the young animal are situated close to the kidneys, on the dorsal wall of the abdomen, but which pass back-

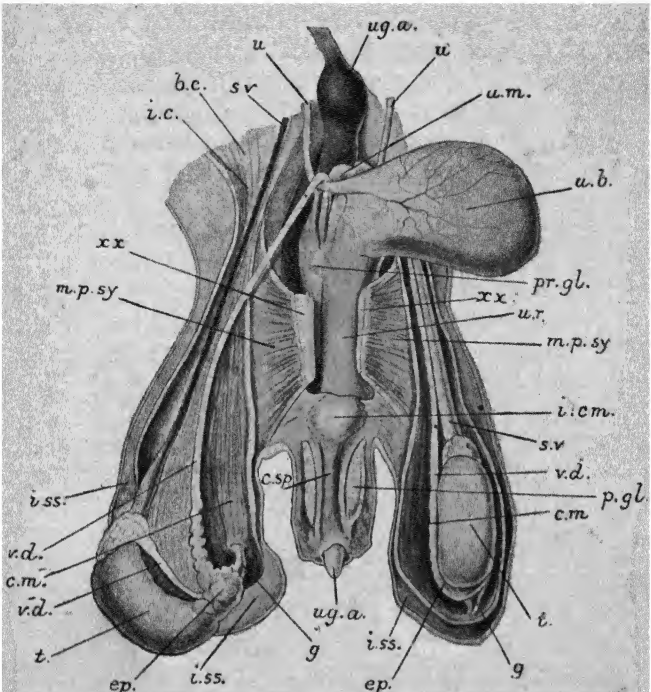


FIG 163 —Posterior part of the previous dissection Scrotal sacs have been fully exposed on both sides, and the pelvic symphysis has been cut through The urinary bladder is turned over to the left side

b c body-cavity, *c m* cremasteric muscle, *c sp* corpus spongiosum, *ic* inguinal canal, *iss* inner surface of the scrotal sac, *ic m* ischio cavernous muscle, *m p sy* muscle inserted into the pelvic symphysis, *p gl* perineal gland, *ug a* urinogenital aperture, *ur* urethra *x x* cut ends of the bones forming the pelvic symphysis Other letters as in the preceding figure (After Roseler and Lamprecht)

wards and downwards as the animal approaches maturity until they come to lie each in a *scrotal sac* (p. 444), situated at the side of the urinogenital opening. The cavity of

each scrotal sac is in free communication with the cavity of the abdomen by an opening—the *inguinal canal.* A convoluted *epididymis* closely adherent to the spermary and connected with the distal end of the scrotal sac, forms the proximal part of the *spermiduct* or *vas deferens* (Fig 162, *v. d*), which, together with the blood-vessels and nerves of the spermary, passes through the inguinal canal: it then loops round the corresponding ureter, and extends back between the neck of the bladder and a median sac on the dorsal side of the latter known as the *uterus masculinus* (*u. m*). The neck of the bladder is continued backwards, through the pelvic cavity, as the *urinogenital canal* or *urethra* (*ur*), on the dorsal side of which, just in front of a rounded elevation, is an aperture by means of which the uterus masculinus and vasa deferentia open into it.

A *prostate gland* (Fig. 163 *p gl*), consisting of several lobes, is embedded in the walls of the uterus masculinus and opens by small ducts on either side of the elevation just referred to, and a pair of smaller, ovoid *Cowper's glands* communicate with the urinogenital canal further back

The terminal part of the urethra traverses the copulatory organ or *penis* (*p*); that part of its wall which in the retracted condition is ventral is constituted by a soft vascular portion, the *corpus spongiosum* (*c. sp*), while the opposite surface is strengthened by two harder bodies, the *corpora cavernosa,* which are closely applied together through the greater portion of their length, but diverge proximally and are attached to the ischia.

In both sexes a pair of *perineal glands* (Fig. 163, *p. gl*) open on the perineal spaces (p 444), and two larger *rectal glands* (*r. gl*) lie at the side of the rectum

In the female the *ovaries* (Figs. 164 and 165, *ov*) are small ovoid bodies attached by peritoneum to the dorsal wall of the abdomen behind the kidneys. The mode of

development of the ova is illustrated in the accompanying figure (Fig. 164). The cells of the germinal epithelium (*KE*) grow inwards amongst the connective-tissue stroma of the ovary in the form of clustered masses which become separated off from the periphery; certain of these cells (*U*) increase in size more than the others, and give rise to the *ova*, while the smaller cells form an investment or *follicle* (*G*) round them, and may serve for the nutrition of the larger cells. The investing cells multiply, and a cavity (*S*) containing a fluid (*Lf*) is formed in the middle of each follicle. These *ovarian follicles* (p 207) are in Mammals usually called the Graafian follicles. When ripe, the ovum, surrounded by a vitelline membrane, is shed into the abdominal cavity by the expansion and bursting of the Graafian follicle[1]; it then passes into the cœlomic aperture of the oviduct (Fig. 165, *fl. t'*).

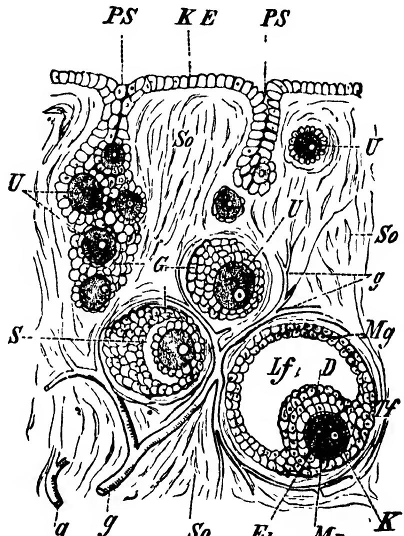


FIG. 164 —Section through a portion of the ovary of a Mammal

Ei ripe ovum, with its germinal vesicle (*K*) and germinal spot, *KE*, germinal epithelium ingrowths from which extend into the stroma of the ovary, which is penetrated by blood-vessels (*g*, *g*), *Lf* fluid, *Mp* Zona pellucida, showing radiated structure, *S* cavity, *U*, *U*, primitive ova. (From Wiedersheim's *Comparative Anatomy*)

[1] After the ova are discharged, a proliferation of cells into the follicles takes place, and gives rise to the so-called *corpora lutea*.

The oviducts, instead of remaining separate along their whole length, are fused distally to form a wide, median portion, the *vagina* (Figs 165, and 166, *va*), opening into the urinogenital canal or *vestibule* (*vb*), with which the bladder communicates and which opens externally at the *vulva* (Fig. 166, *u g. a*). Into the inner end of the vagina, the paired, thick-walled *uteri* (Fig. 165, *r. ut. l. ut*), or middle portions of the oviducts, open by separate thick-walled apertures.

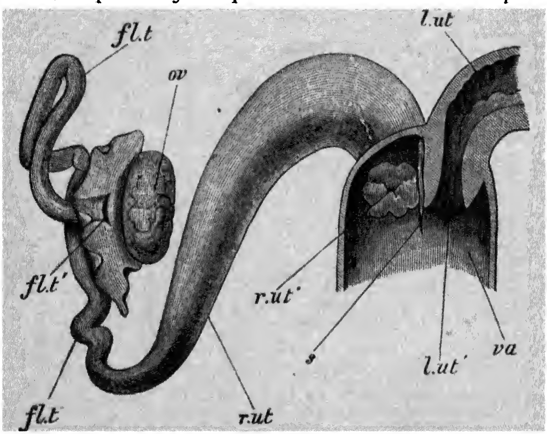


FIG 165 —The anterior end of the vagina, with the right uterus, Fallopian tube, and ovary of the Rabbit (× about 2) Part of the ventral wall of the vagina is removed, and the distal end of the left uterus is shown in longitudinal section *fl t* uterine tube, *fl t'* its cœlomic aperture *l ut* left uterus, *l ut'* aperture of same (os uteri) into vagina, *ov* right ovary, *r ut* right uterus, *r ut'*. aperture of right uterus into vagina, *s*. vaginal septum, *va* vagina (From Parker's *Zootomy*)

The eggs undergo development in the uteri, which vary in size according to whether or not they contain embryos, and according to the stage of development of these. Each uterus is continued forwards as a narrow, slightly coiled tube—the anterior section of the oviduct, or *uterine tube* (*fl. t*), which communicates with the cœlome by a small aperture (*fl. t'*) surrounded by a wide, membranous

funnel with thin walls and folded margins, which is applied to the outer surface of the corresponding ovary. On the ventral wall of the hinder or proximal end of the urinogenital canal is a small, hard, rod-like body, the *clitoris* (Fig. 166, *g. cl*), corresponding to the penis of the male, and strengthened by two small *corpora cavernosa* (Fig. 166, *c c*) attached at their proximal ends to the ischia.

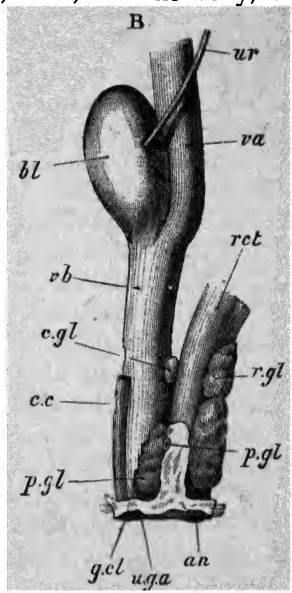


FIG 166 —The urinogenital organs of a female Rabbit The kidneys and proximal ends of the ureters, ovaries, Fallopian tubes and uteri are not shown
c c corpus cavernosum, *c gl* Cowper's gland, *g cl* apex of clitoris, *p gl* perineal gland, *p gl'* aperture of the duct of the perineal gland on the perineal space, *r gl* rectal gland, *v b* vestibule Other letters as in the preceding figures (From Parker's *Zootomy*)

The rabbit is viviparous. The minute ova are discharged into the uterine tubes, where they become fertilised, and then pass into the uterus, in which each develops into a *fœtus*, as the intra-uterine embryo is termed, and is nourished by means of an organ known as the *placenta*, which will be described in Chapter XI. The young animal escapes from the uterus in a condition in which all the parts have become fully formed, except that it is practically hairless; the eyelids are at first coherent. As many as eight or ten young are produced at a birth, and the period of *gestation*, *i.e.*, the time elapsing between the fertilisation of the ovum and the birth of the young animal, is thirty days. Fresh broods

may be born once a month throughout a considerable part of the year, and, as the young rabbit may begin breeding at the age of three months, the rate of increase is very rapid.

Characters of the Class.—In addition to the characters mentioned at the beginning of this chapter, we are now in a position to refer to some other important features which characterise the **Mammalia** as a class. The Mammalia (even those of them that, like the Whale, live in water) are air-breathing Vertebrates. The body-cavity is divided into two portions—thorax and abdomen—by a transverse muscular partition, the diaphragm. The heart is completely divided into two halves, a right and a left, between which there is no aperture of communication after birth. Each half consists of an auricle and a ventricle, opening into one another by a wide opening guarded by a valve composed of three membranous cusps on the right side, two on the left. The right ventricle gives off the pulmonary artery, the left gives off the single aortic arch, which passes over to the left side. The red blood-corpuscles are non-nucleated and usually circular.

In nearly all mammals (whether they be long-necked like the camel or short-necked like the cat) the number of cervical vertebræ is seven. The ends of the vertebræ are covered with independently developed discs of bone—the epiphyses, and between successive vertebræ are discs of fibro-cartilage called intervertebral discs. The skull has two occipital condyles for articulation with the atlas, instead of the single condyle of the Reptiles and Birds; and the lower jaw articulates directly with the skull in the squamosal region without the intermediation of a separate quadrate as in Birds and Reptiles. There is a chain of three small ossicles in the middle ear.

The brain has reached a higher degree of differentiation than in any other class of Vertebrates. The two cerebral hemispheres, in all except the Prototheria and Marsupials (see p. 514), are connected together by a band of transverse fibres, the corpus callosum, not represented in the other Vertebrates. The dorsal part of the mid-brain is divided into four optic lobes, the corporal quadrigemina. On the ventral side of the hind-brain is a transverse band of fibres, the pons Varolii, by which the lateral portions of the cerebellum are connected together.

The kidneys are derived from the metanephros, and the ureters, except in Prototheria, open into the bladder, and not directly into a cloaca.

With the exception of the Prototheria, Mammals are all viviparous. In all the higher mammals the ova are minute, and after fertilisation are retained in the uturus, in which each develops into a fœtus. The fœtus is nourished from the blood system of the parent through a special development of the allantois and the lining membrane of the uterus, termed the placenta. After birth, the young ones are nourished for a longer or shorter period by the milk or secretion of the mammary glands of the parent.

Classification.—The class Mammalia is divided into three great primary divisions or sub-classes, which are called :—

I. Prototheria, or primitive mammals.
II. Metatheria, or modified mammals.
III. Eutheria, or perfect mammals.

The **Prototheria** include two extraordinary animals, the Duck-billed Mole and the Spiny Ant-eater, which are found only in Australia, New Guinea, and Tasmania. In these animals large eggs containing abundant yolk and

with a firm shell are laid in a nest and incubated by the mother. The oviducts are large and separate throughout, opening along with the intestine into a common cloaca, as is the case with Birds and Reptiles. The ureters do not open into the bladder as they do in all other Mammalia, but they, as well as the bladder, open separately into the cloaca. After they are hatched the young receive milk from the mother. There is no teat, but the fluid from the mammary glands seems to soak in the hair, and thence is sucked by the young. These

Fig 167 —Duck billed Mole (*Ornithorhynchus anatinus*) (After Vogt and Specht)

animals are of great interest from an evolutionary point of view, as showing many affinities with the Reptiles, from some of which the great group of Mammals is believed to have been evolved. The skeleton also presents many interesting features of agreement with the Reptiles; there are large coracoids articulating with the sternum, a T-shaped episternum, and a pair of epipubic (marsupial) bones

The section **Metatheria** includes all the pouch-bearing mammals, such as the Opossums of America, and the

Dasyures, the Bandicoots, the Wombats, the Phalangers, and the Kangaroos of Australia and the neighbouring islands. In these animals the egg is very small, and the ovarian tube is divided into an upper part of narrow diameter called the Fallopian tube and a lower, wider

FIG. 168.—The Rock Wallaby (*Petrogale xanthopus*) with young in pouch. After Vogt and Specht.

part called the uterus. In the uterus the small egg is retained for some time and develops a close adhesion to its wall for obtaining nourishment.

The young are born in a rudimentary and helpless condition and are placed by the mother in a pouch formed by a fold of skin on the lower part of her body, whence the name Marsupials (Lat. *marsupium*, a pouch) often given to these animals. The young are quite incapable of feeding themselves, but each becomes attached by its mouth to the opening of one of the ducts of the milk-gland, and the mother squeezes the milk-gland by compressing the muscles of the belly and thus forces milk down their throats. These animals also, like the Prototheria, possess a pair of epipubic (sesamoid) bones running forward from the pubes.

The highest division of the mammals, the **Eutheria,** comprises the great majority of mammals. In them the egg is exceedingly small. The upper part of the oviduct is narrow, but the uterus is greatly enlarged, and the egg not only remains there for a long time, but as the fœtus is developing, a special organ, called the *placenta*, is formed. This organ is the result of a great development of the allantois, which grows out and becomes interlocked with depressions in the wall of the uterus. The middle portions of the oviducts, or uteri, are sometimes quite separate, as in the rabbit (p. 508), sometimes partly united, as in the cat, rarely completely united, as in monkeys and man. The lowest part of the oviducts are, however, completely joined and form a single passage, the vagina.

Leaving aside the fossil forms, the Eutheria are usually arranged in the following eleven orders :—

1. *Edentata*, comprising the Sloths, Ant-eaters, and Armadillos of South America.

2. *Effodientia*, the Scaly Ant-eaters and the Cape Ant-eaters of Africa.

3. *Insectivora*, including the Moles, Shrews, and Hedgehogs.

4. *Carnivora*, or the Cats, Dogs, Bears, Otters, and the Seals and Walruses.

5. *Cetacea*, including the Whales, Porpoises, and Dolphins.

6. *Ungulata*, a very large order, comprising, among other forms, the Horses, Tapirs, and Rhinoceroses, the Ruminants (Camels, Oxen, Sheep, Goats, Antelopes, Giraffes, and Deer), the Pigs and Hippopotami, and the Hyraxes.

7. *Proboscidea*, or the Elephants.

8. *Sirenia*, or Dugongs and Manatees (Sea-cows).

9. *Rodentia*, a large order, including, among others, the Rats and Mice, Hares and Rabbits, Squirrels, Beavers, and Porcupines.

10. *Chiroptera*, or Bats, and Fruit-eating Bats ("Flying Foxes").

11. *Primates*, comprising the Lemurs, Monkeys, Baboons and Apes, and Man.

We cannot enter here into a description of the structural peculiarities exhibited by members of all these orders, but there are certain points of organisation which even an elementary student of Zoology may like to make acquaintance with. We shall therefore deal with some of the more important features in the following pages, which, it is hoped, will enable him to understand better the Doctrine of Evolution, dealt with in a subsequent chapter (p. 608, *et seq.*).

The **Carnivora** are distinguished above all by their teeth. Their incisors are small and insignificant, but their canines (teeth which are quite absent in a typically herbivorous mammal like the rabbit) are large and pointed, and it is with these the animal seizes and kills its prey. The premolars have cutting edges, and the molars are mostly broad and crushing. The last premolar in the upper jaw and the first molar in the lower

jaw are very large and blade-like, and bite on one another like a pair of scissors, and are called the carnassial teeth. The skull of the Dog, on account of its larger size, is sometimes substituted for that of the Rabbit for detailed study of a mammalian skull; and in any case it would be a most useful exercise for a student after having studied the skull of the Rabbit (pp. 445–454) to trace out the various bones and find the different foramina on the skull of the Dog, noting any points of difference that he may come across. For this study no separate description is required, as the figures here given will afford all the help the student may need.

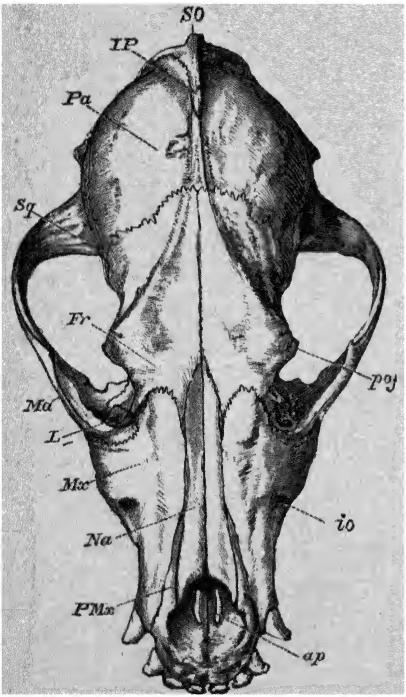


FIG 169 —Dorsal view of the cranium of a Dog (*Canis familiaris*), half natural size
So supra-occipital, *IP* inter-parietal, *Pa* parietal, *Sq* squamosal *Fr* frontal, *L* lacrymal, *Ma* malar or jugal, *Mx* maxilla, *Na* nasal; *Pmx* premaxilla, *ap* anterior palatine foramen, *io* infra-orbital foramen, *pof* postorbital process of frontal bone. (From Flower's *Osteology of the Mammalia*)

As special features in which the skull of Dog differs from that of Rabbit might be mentioned the prominent sagittal and lambdoidal crests, the deep temporal fossæ,

the strong and greatly arched zygoma, and the greater development of the facial region. The glenoid cavity

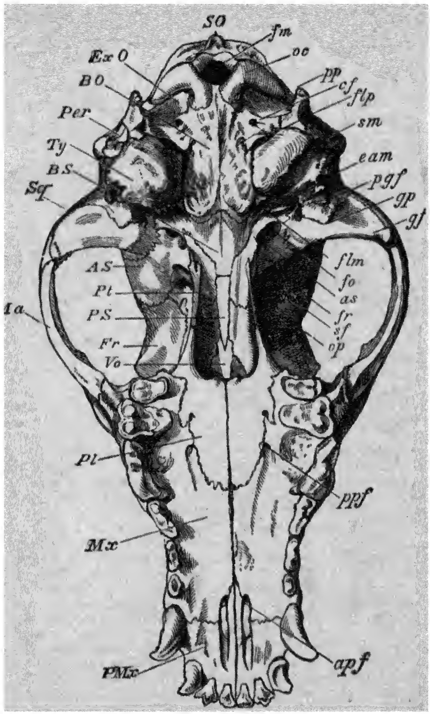


FIG 170.—Ventral view of the cranium of a Dog, half size
Exo exoccipital; *BO* basioccipital, *Per* mastoid portion of periotic, *Ty* tympanic bulla, *BS* basisphenoid; *Sq* zygomatic process of the squamosal; *As* alisphenoid, *Pt* pterygoid, *Ps* presphenoid, *Vo* vomer, *Pl* palatine; *fm* foramen magnum, *oc* occipital condyle, *pp* paroccipital process, *cf* condylar foramen for the XII nerve, *sm* stylomastoid foramen for the exit of the VII nerve, *eam* external auditory meatus, *pgf* postglenoid foramen, *gp* postglenoid process, *gf* glenoid fossa, *flm* foramen lacerum medium, through which the internal carotid passes to the brain, *fo* foramen ovale, for the exit of the mandibular division of the V nerve, *as* posterior opening of alisphenoid canal (through which external carotid artery runs for part of its course), *fr* foramen rotundum (for the maxillary division of the V nerve) and anterior opening of alisphenoid canal, *sf* sphenoidal fissure or foramen lacerum anterius for III, IV, ophthalmic division of V, and VI nerves, *op.* optic foramen for II nerve; *ppf* posterior palatine foramen Other letters as in the preceding figure (From Flower's *Osteology of the Mammalia*)

is in the form of a transverse groove to the shape of which the transversely elongated condyle of the mandible is adapted. The dental formula is $i\,\frac{3}{3}\,c\,\frac{1}{1}\,pm\,\frac{4}{4}\,m\,\frac{2}{3}=42$.

Among the members of this order, the ends of the digits are provided with curved claws, which may be very long and sharp, and are capable, when not in use,

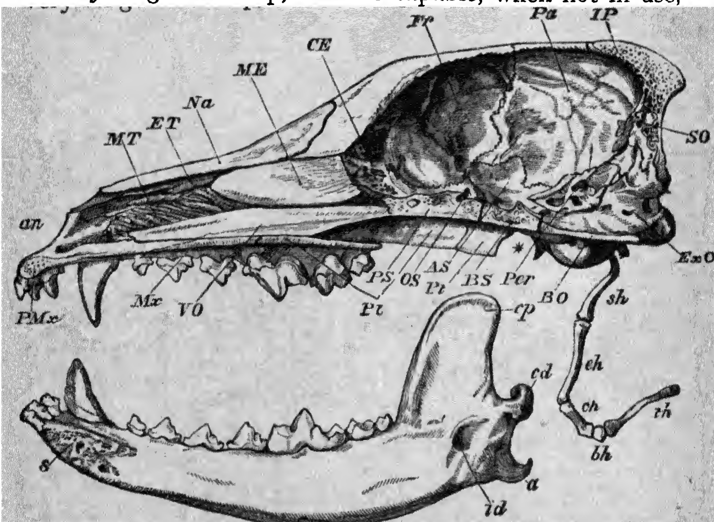


FIG 171 —Longitudinal and vertical section of the skull of a Dog with mandible and hyoid arch (× ½)
an anterior narial aperture, *MT*. maxillo turbinal bone, *E T* ethmo turbinal, *ME* mesethmoid, *CE* cribriform plate of the ethmoid, *Per* petrous portion of the periotic bone, *os* orbitosphenoid, *sh* stylohyal, *eh* epihyal, *ch* ceratohyal, *bh.* basihyal, *th* thyrohyal, *s* symphysis of mandible, *cp* coronoid process, *cd* condyle, *a* angle, *id* inferior dental canal The mandible is displaced downwards to show its entire form, the * indicates the part of the cranium to which the condyle is articulated. (From Flower's *Osteology of the Mammalia*)

of being retracted into a sheath of skin (as in the cats); or relatively short and blunt, in which case they are incompletely or not at all retractile. The Otter differs from the rest in having short limbs with the toes connected by webs of skin. The Seals and Walruses show greater or lesser adaptation for an aquatic life.

The Dog, *Canis familiaris*, the Wolf, *C. lupus*, the Jackal, *C. aureus*, and the Fox, *C. vulpes*, are all species of the same genus, being distinguished from each other by size and slight peculiarities of hair, etc. ; and similarly the Lion, *Felis leo*, the Tiger, *F. tigris*, the Leopard or Panther, *F. pardus*, so closely resemble the common cat, *F. catus*, that they also are regarded as different species of one genus. The differences in the colour of skin which help to distinguish them are in all probability due to

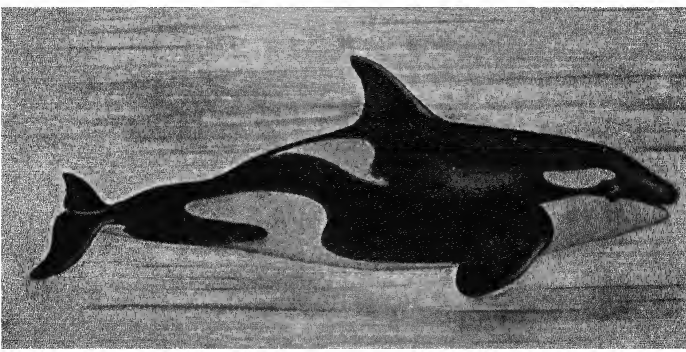


FIG 172.—Killer (*Orca gladiator*). (After True.)

the fact that the colours are protective, enabling the animals when in their natural surroundings to come close to their prey without the latter noticing them. Lions live as a rule in dry and rather open places, and are of a dun colour which harmonises well with the surroundings ; the stripes of the tiger's skin deceptively resemble the alternating shadows and sunlit spaces of ground found amongst the reeds in which it lives ; the spots of a leopard are unnoticeable amidst the patches of light

and shade caused by the sunlight struggling through the interstices between leaves of trees in a forest.

The **Cetacea**, among which are included the Whales, the largest of existing Mammals, are interesting as showing a complete adaptation to an aquatic mode of life. As is well known, they pass all their life in water and show great differences in structure from all land Mammals in all parts of their body.

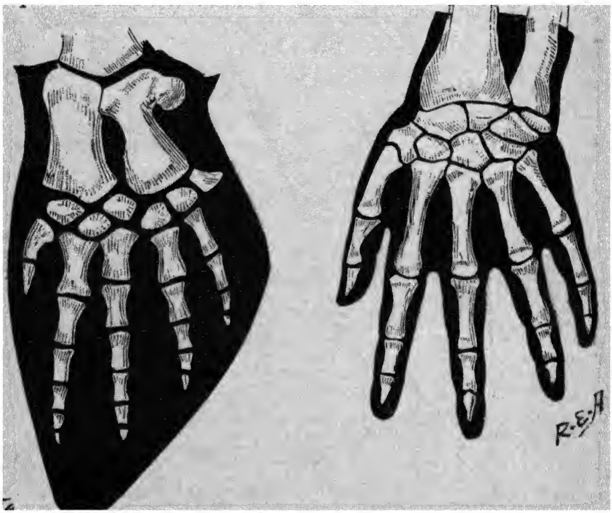


FIG 173 —The paddle of a Whale and the hand of Man compared (From Romanes' *Darwin and after Darwin*)

The body is fusiform, fish-like, tapering backwards to the tail, provided with a flattened tail-fin, which is expanded in the horizontal plane, not in the vertical plane like that of Fishes. Whales progress by moving the tail-fin up and down, whereas the movement in fish is from side to side. A dorsal median fin is usually present. All external trace of hind-limbs has disappeared, though a pair of small bones representing the

pelvic girdle are found embedded in the body. The fore-limbs have become flappers, with the digits devoid of claws and bound together by skin to their very tips. The number of phalanges in each finger is greatly increased. The limb is buried in the body almost to the wrist, yet the skeleton clearly shows that it consists of the same bones as in other Mammals, and has no resemblance with that of the Fishes The mouth is very wide, the nostrils are situated on the summit of the head, and the auditory pinna is absent. Hairs are almost completely absent, only one or two being found in the region of the lips in the embryo only. The body is covered with a thick layer of fat termed blubber, which preserves the heat of the body and protects the animal against the cold of the water.

In the great group of the **Ungulata,** or hoofed animals, all power of grasping with the limbs is absent, and all the four "feet" are purely adapted for running, the "toes" being encased in hard blunt nails which are called hoofs The thigh and the upper arm are more or less buried in the body, whilst the heel and the wrist are raised in walking so that the animal goes along on the tips of its toes. The bones of the wrist are arranged in transverse rows, the members of the two adjacent rows alternating with one another. The first digit in both fore- and hind-limbs is always absent. The Ungulates are divided into two great groups—(1) the **Perissodactyla,** in which there is an odd number of toes and in which the true central axis of both arm and leg passes through the centre of the third finger or toe (Fig. 174), and (2) the **Artiodactyla,** or even-toed, in which the third and fourth digits of each foot form a symmetrical pair, and in the majority are the only completely developed digits.

In the **Elephants,** the largest of existing terrestrial Mammals, the limbs are much more typically developed

than in the true Ungulates. There are five comparatively short digits, enclosed in a common integument in each foot, most of which end in broad flat nails. The limbs are very stout and pillar-like, the thighs and upper arms being quite free from the body, and not buried in the general contour of the body, as in most other Mam-

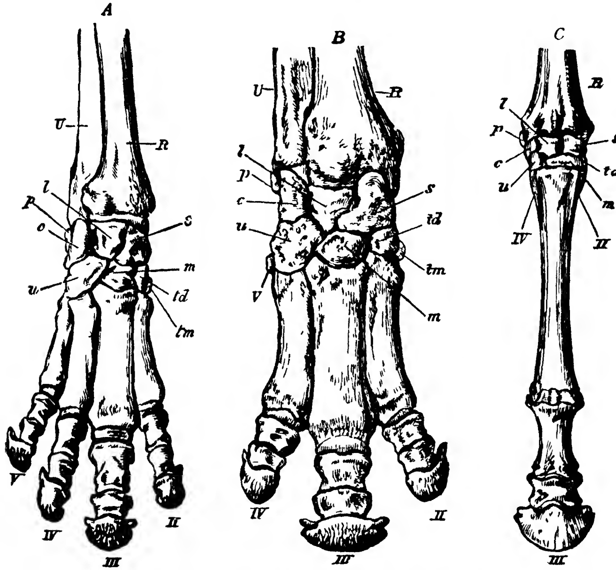


FIG 174.—Bones of the fore-foot of existing Perissodactyles *A*, Tapir, *Tapirus indicus*, × ¼, *B*, Rhinoceros, *Rhinoceros sumatriensis*, × ⅕; *C*, Horse, *Equus caballus* × ⅙

R radius; *U* ulna, *s* scaphoid (radiale); *l* lunar (intermedium), *c* cuneiform (ulnare); *p* pisiform, *tm* trapezium (first distal carpal), *td* trapezoid (second distal carpal); *m* magnum (third distal carpal), *u* unciform, fused fourth and fifth distal carpal II—V, second to fifth digits. (From Flower's *Osteology of the Mammalia*)

mals. The trunk, or proboscis, is really a long flexible snout, at the end of which are situated the nostrils; and in the Indian elephant a finger-like lip is attached to the upper margin of the end of the trunk. The tusks are the incisor teeth of the upper jaw. The canines are

absent. The molars are so large that the jaws cannot at one time accommodate more than at the most two and a part of a third. These molars being the only functional teeth, the elephant is popularly described as having different teeth for mastication and for show.

The **Rodentia** or Gnawers (Lat. *rodo*, to gnaw) are all vegetable feeders and are sharply marked off from other

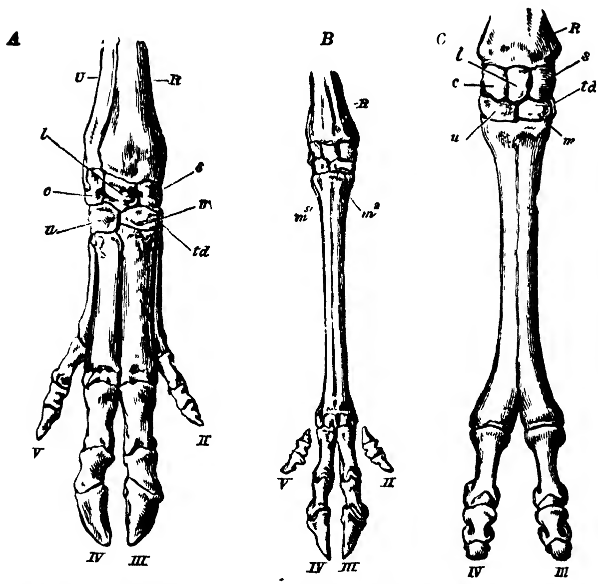


FIG. 175 —Bones of the fore-foot of some Artiodactyla *A*, Pig, *Sus scrofa*, × ⅓, *B*, Red deer, *Cervus elaphus*, × ¼, *C*, Camel, *Camelus bactrianus*, × ¼ Letters as in the preceding figure. (From Flower)

Mammals by the character of their teeth (which has been fully described in the case of the Rabbit, see p. 471). Their incisors, which are adapted for gnawing, are never more than two in number in the lower jaw and in most of them there are only two in the upper jaw also. There

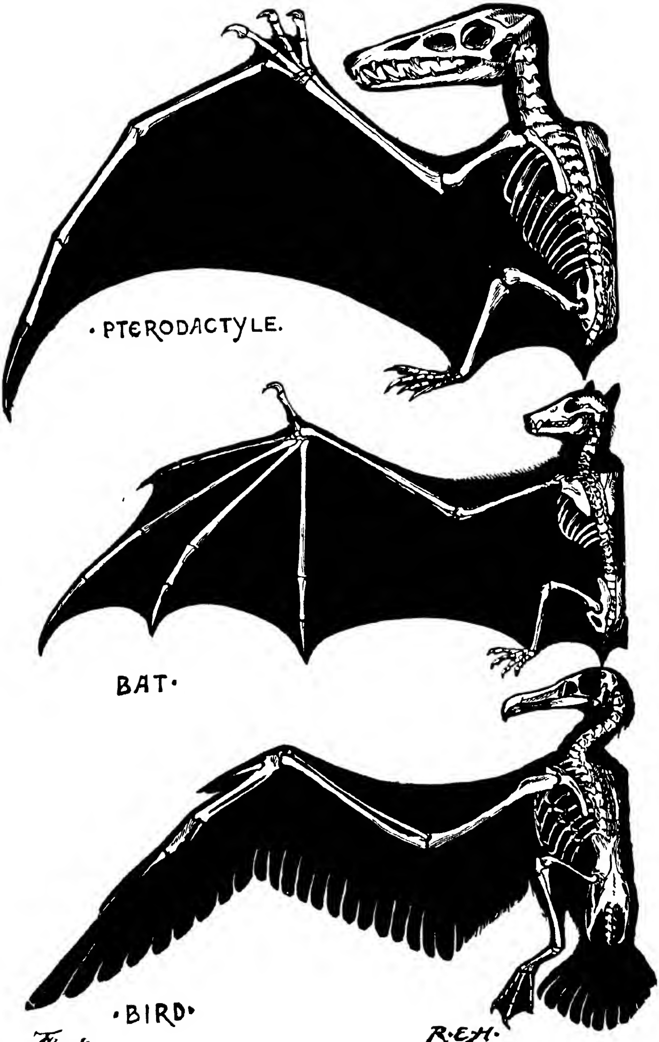


Fig 176.—Wing of an extinct flying Reptile, Bat, and Bird compared (From Romanes' *Darwin and after Darwin*)

are no canines, so that there is a considerable space or diastema between the front and the back teeth.

The **Chiroptera** (Gr. Χειρ, a hand; πτερόν, wing) or Bats are the only Mammals which are capable of active flight, for which purpose their arms are modified into wings. As in Birds, the fore-arm is bent up on the upper arm, the wrist bent down on the fore-arm; but, unlike the wing of Birds, the flying membrane is of skin and not of feathers. The membrane is stretched chiefly between the fingers of the five-fingered hand, and further extends back to the hind-limbs. Part of the membrane extends down the thighs, and in some even the tail is involved. The hand is enormous, the "little finger" being, as a rule, very greatly elongated, while the thumb alone is small, is not included in the membrane, and ends in a curved claw.

The **Primates**, as stated above, include Lemurs, Monkeys, and Man. The order is characteristically arboreal—that is to say, most of its members live among trees, climbing from branch to branch. The thigh and the upper arm are quite free from the body, and the whole sole of the foot and palm of the hand are placed on the ground in walking. There are five fingers and five toes, some of which at least have flat nails. The big toe is shorter than the rest, and, except in Man, can be separated from them so as to be used for grasping, in the same way as can the thumb in Man and most Monkeys. Thus at one time in the History of Zoology Monkeys were wrongly regarded as possessing four hands and placed in a separate order (Quadrumana) from that of Man (Bimana). The eyes are placed in the front of the skull instead of at the sides of the head, and the jugal joins the postorbital process of the frontal, so that the orbit is surrounded by a bony ring. There are two large mammæ situated on the breast only (an extra

pair on the abdomen found only in some Lemurs being vestigial).

The order is divided into two sub-orders, the **Lemuroidea,** including the Lemurs, and the **Anthropoidea,** including the true Monkeys and Man. The Anthropoidea are distinguished by the fact that the bony ring surrounding the orbit sends inward a plate which completely separates off the orbit from the temporal fossa. The cerebral hemispheres conceal the cerebellum when the brain is viewed from above. The placenta is at first spread all over the surface of the ovum, but later becomes concentrated on one part of the wall of the uterus (metadiscoidal placenta), and is deciduate (see p. 599). There are never more than two mammæ. Leaving aside the Marmosets and the Howling and the Spider Monkeys of America, we come to the old world Monkeys which belong to the families *Cercopithecidæ* and *Simiidæ*. The former include the Macaques, the Baboons, and the Sacred Langur (*Semnopithecus*) of India. They have their legs as long as their arms, or longer, and go habitually on all fours. There are always brightly coloured bare patches of skin (callosities) over the ischia, on which the animals rest when they assume a sitting posture, and there is in almost every case a well-developed tail. In the Simiidæ or Man-like Apes the tail is completely absent. There are four genera known, *Hylobates* (Gibbons), *Simia* (Orang-utan), *Gorilla* (Gorilla), and *Anthropopithecus* (Chimpanzee). In all these the arms are longer than the legs, and they walk in a semi-erect manner. The Gibbons can walk in an upright manner holding out their long arms as if they were balancing poles; in the others, though in walking on the ground the body may be held in a semi-erect position with the weight resting on the hind-limbs, the long fore-limbs reach the ground and are used as crutches.

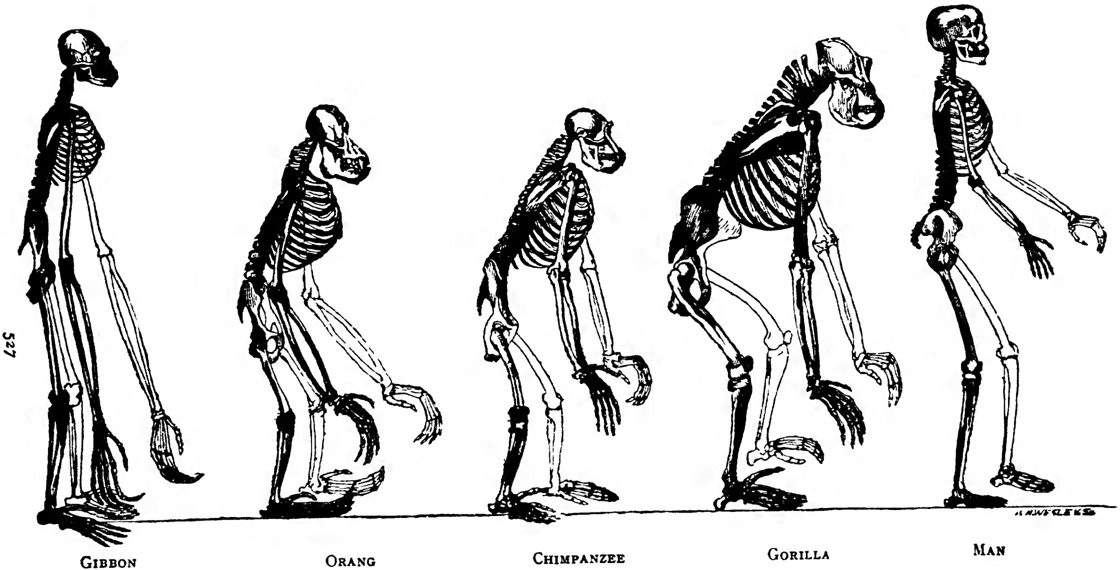


FIG 177—Skeletons of the Anthropoid Apes and Man. (From Huxley's *Man's Place in Nature*)

(Photographically reduced from diagrams of the natural size (except that of Gibbon, which was twice the natural size).

Man (*Homo sapiens*) is distinguished above all by the great size of the brain, which is about double the size of that of the highest monkey, and by the modification of the hind-limbs to support the body and enabling him to walk erect. The great toe is no longer used for grasping. The hands being thus entirely set free were used to acquire a variety of experiences, and the intelligence of man awakened. Another great factor which must undoubtedly have stimulated the mental development of Man is his habit of living together in societies and undertaking concerted action for the good of the community. To this power of combination may be traced the evolution of language and morals. "Man did not make society, it was society that made Man."

PRACTICAL DIRECTIONS

A. Skeleton.

The skeleton of a young rabbit, about six weeks old, as well as that of an adult, should be obtained for examination: the former is the more important of the two for making out the individual bones, which can all be separated from one another by prolonged maceration in water, or by boiling for a short time. In the adult skeleton the bones are best kept in their natural connection. An additional skull should be prepared, and a longitudinal vertical section made of it with a fine saw; but as it is difficult to do this very accurately and perfectly in the rabbit, owing to the delicacy of some of the bones, the skull of a young dog or cat may be used for the purpose.

Work through the account of the skeleton given on pp. 444–466 as well as of the teeth on pp 471–473, comparing the form, number, and arrangement of the teeth in the herbivorous rabbit and the carnivorous dog or cat, noting the presence of *canines* in the two last mentioned and other points referred to on p. 518.

The Vertebral Column.—Sketch (*a*) any cervical vertebra from the third to the sixth, from the front or back; (*b*) *atlas*, from the dorsal surface; (*c*) *axis*, from the side; (*d*) any thoracic vertebra, say the fifth, from the side; (*e*) any

lumbar vertebra, say the second, from the side; (*f*) sacrum, ventral aspect.

The Skull—(*a*) Sketch the side view of the skull, with the lower jaw, naming the various bones, bony processes, and important nerve-foramina.

(*b*) Sketch the ventral aspect of the skull

(*c*) Sketch the outer and inner aspects of the *periotic* bone, from a separate specimen of the bone, from which the tympanic has been detached

(*d*) Sketch the bones of the olfactory capsule as seen in a longitudinal vertical section of the skull.

Ribs and Sternum.—Sketch the sternum and ribs as seen from the ventral aspect.

Pectoral Girdle and Fore-limb—(*a*) Sketch the *scapula* as seen from the dorsal aspect.

(*b*) Sketch the *humerus*, *radius and ulna*, *carpals*, *metacarpals* and *phalanges*, as seen in the anterior aspect of the fore-limb

Pelvic Girdle and Hind-limb—(*a*) Sketch the pelvic girdle from the ventral aspect, showing the *symphysis* and the *ilium*, *ischium*, *pubis*, *acetabulum*, and *obturator foramen* of each side

(*b*) Sketch the *femur*, *tibia* and *fibula*, *tarsals*, *metatarsals* and *phalanges*, as seen in the anterior aspect of the hind-limb.

B Superficial dissection, and removal of the brain.

The specimen used should be over three months old. Place it in a sufficiently large jar or box with a close-fitting lid together with a piece of cotton-wool well soaked in chloroform, and leave it until a short time after all movements have ceased. A pair of *bone-forceps* (p 13) will be required.

1. Fix the animal on its back on the dissecting-board by inserting large pins or nails through the limbs. If you wish to inject the arteries, cut through the skin on the inner side of one of the thighs, reflect it, and with the seeker expose the femoral artery (p. 487); or if your specimen is a small one, expose one of the carotid arteries (p. 485) instead, by carefully cutting through the skin along the middle ventral line of the neck. Pass a piece of thread round the artery thus laid bare, and make a small slit in it with the fine scissors distally to the thread. Insert and tie in a cannula, directed towards the body, and first inject a little strong formaline (1 part formaline and 2 parts water), following this with the coloured starch injection-mass

(p. 105), which will force the formaline into the capillaries and help to preserve the specimen : this method is of special advantage for the subsequent examination of the enteric canal. The veins need not be specially injected, as they will be naturally injected with blood.

Make a median longitudinal incision through the skin in the sternal region, and continue the cut backwards to the pelvic symphysis and forwards to the mandibular symphysis ; then dissect away the skin from the underlying muscles over the whole ventral surface, being careful not to injure any of the larger blood-vessels (*e g* , the jugular veins in the neck). Note :—

1. The thin *cutaneous muscle*, part of which you have very likely removed together with the skin , and in the adult female, the *mammary glands* (p. 467)—trace the main ducts of some of these to their apertures on the teats

2. In the neck :—*a*, the *trachea* and *larynx* (p 479), to see, which and the following structures clearly the cervical portion of the cutaneous muscle should be dissected away and the underlying parts carefully separated with a seeker ; *b*, the *hyoid bone*, situated in a mass of muscle just anterior to the larynx ; *c*, the *submaxillary glands* (p. 474) ; and *d*, the large *external jugular veins* (p. 487)

3 In the thorax :—*a*, the *sternum* and *xiphisternum* ; *b*, the small *clavicles* (p 460) ; *c*, the *pectoral muscles* ; *d*, the vertebral and sternal portions of the *ribs* and the *external intercostal muscles* ; and *e*, the blood-vessels and nerves going to the fore-limbs

4. In the abdomen :—*a*, the muscles of the abdominal wall, separated in the middle ventral line by a whitish fibrous band ; *b*, *Poupart's ligament* (p. 467) ; *c*, the blood-vessels and nerves passing beneath Poupart's ligament to the hind-limbs.

II. On the same day on which the animal is killed, remove the skin from the dorsal surface of the head and anterior part of the neck, and also the muscles covering the anterior cervical vertebræ. A membrane between the skull and first vertebra will then be exposed : cut through this, and part of the *spinal cord* will be seen. With the bone-forceps cut away the arches of the first three or four vertebræ and the roof of the skull—taking particular care in the auditory region—so as to expose the brain : note the *olfactory lobes*, *cerebral hemispheres*, *cerebellum*, and *medulla oblongata*, and also the *dura mater* and *pia mater*. Then cut through the spinal cord about a quarter of an inch beyond its junction with the brain, lever up the latter with the handle of a scalpel

and carefully cut through all the nerves arising from it and separate it from the cranial walls, working from behind forwards. Dissect away the olfactory lobes from their attachments, remove the entire brain, and place it in 3 per cent. formaline or in strong spirit.

The animal may be preserved from day to day by wrapping a cloth round it soaked in 3 per cent formaline or strong methylated spirit and placing it in a closed vessel.

C. Dissection of the abdomen.

I. Once more pin the animal down, ventral side uppermost, and make an incision along the middle line of the abdominal muscles from the xiphisternum to the pelvic symphysis, so as to open up the abdominal cavity. From the anterior extremity of the incision make transverse cuts, and turn back the flaps of muscle. Note :—

1. *a*, The *peritoneum* , *b*, the *diaphragm*, with its muscles and central tendon ; *c*, the pink *lungs*, seen through the latter : make a small aperture in the diaphragm on one side of the median line and note the collapse of the corresponding lung.

2. *a*, The *liver*, *stomach*, *small intestine*, *cæcum*, *colon*, and *rectum* (pp 474–478) ; *b*, the *urinary bladder* ; *c*, the *scrota sacs* in the male ; and—by turning aside the intestines—*d*, the *kidneys* ; in the female *e*, the *ovaries* and *oviducts* (varying much in size according to age).

3. *a*, The characters and relations of the *lobes of the liver* (compare Fig 151), and the folds of peritoneum which attach the liver to the diaphragm ; *b*, the *gall-bladder* ; *e*, the *gullet*, and its entrance into—*f*, the *stomach* (note its cardiac and pyloric portions) ; *g*, the *spleen*

4 *a*, The parietal and visceral layers of the *peritoneum* and the various subdivisions of the *mesentery* ; *b*, the U-shaped *duodenum*, passing into the *ileum*, which ends in the *sacculus rotundus*, and the connection of the latter with the proximal end of—*c*, the *cæcum*, at the distal end of which is the *vermiform appendix*, while proximally it passes into—*d*, the *colon*, continuous with—*e*, the *rectum*, which enters the pelvic cavity to open by the anus.

II Turn over the stomach to the animal's right side and make out—

1. *a*, The *postcaval vein*, passing from the pelvis forwards, near the ventral surface of the backbone, through a notch in the liver to the diaphragm ; *b*, the *dorsal aorta*, running partly above, partly alongside, the postcaval ; *c*, the *cœliac artery*, given off from the aorta about an inch posteriorly to

the diaphragm—trace its main branches; *d*, the *anterior mesenteric artery*, arising about half an inch further back than the cœliac—trace its main branches (Fig 151). Note the *cœliac plexus* (p 498).

2 *a*, The left *kidney*, with its artery, vein, and *ureter*; *b*, the yellowish left *adrenal*, anterior to the origin of the renal artery and vein; *c*, the left *ovary*, *uterine tube*, and *uterus* in the female.

3. *a*, The small *posterior mesenteric artery*, leaving the aorta a short distance posteriorly to the left kidney and supplying the rectum; *b*, the *posterior mesenteric vein*, in the mesentery of the rectum.

III. Turn the intestines over to the animal's left side and spread out the duodenum, putting its mesentery slightly on the stretch but taking care not to rupture it, so as to make out—

1. *a*, The large *anterior mesenteric* vein, into which the posterior mesenteric vein opens, *b*, the *pancreas* and its *duct*, opening into the distal limb of the duodenal loop an inch or so beyond the bend.

2. *a*, The right *kidney*, partly overlapped by the caudate lobe of the liver, and its *ureter*; *b*, the right *adrenal*.

IV. Replace the intestines in their natural position; cut through the gullet close to the diaphragm, draw the stomach backwards, turn forwards the lobes of the liver, and dissect out the following structures (Fig. 151):—

1. The *common bile-duct*—made up of *cystic* and *hepatic ducts*, and its entrance into the duodenum

2. *a*, The large *hepatic portal vein*, running in the mesentery ventrally to the postcaval, made up by the union of the *mesenteric*, *gastric*, and *splenic veins*, and entering the liver, sending a branch to each lobe, *b*, the transparent *lymphatic vessels* (*lacteals*) in the mesentery.

V. Tie two pieces of thread, about half-an-inch apart, round the portal vein just before it enters the liver (the hepatic artery and bile-duct may be included in the ligature); cut through the rectum just anteriorly to the pelvic cavity, and through the portal vein between the ligatures, as well as through the mesenteric attachments of the stomach and intestine, and remove these from the body entire. Unravel the intestine by cutting or tearing the mesentery—except that part of it in which the pancreas lies—and spread it out on the dissecting-board or in a large dissecting-dish, arranging it so that the various subdivisions may easily be distinguished from one another, and note the length of the

intestine as a whole (about fifteen or sixteen times that of the animal), and the relative length of its five divisions.

Sketch the entire abdominal portion of the canal

VI Remove and cut open the stomach and parts of the small intestine, colon, and rectum: wash thoroughly, and examine under water Remove the cæcum together with a small portion of the ileum and colon, wash it out by directing a stream of water through it, distend with water (it is better to harden it first with formaline) and examine in a dish of water; with the scissors cut away a piece of the wall here and there, between the constrictions and in the appendix Note —

1 The *mucous membrane, muscular coat,* and *peritoneum*

2 The longitudinal ridges or *rugæ* in the stomach, and the *pyloric valve.*

3. The *aperture of the bile-duct,* and the *villi* and *Peyer's patches* (p. 477) in the small intestine

4 *a,* The *Peyer's patches* and *intra-colic valve* in the proximal part of the colon; *b,* the thick *lymphoid tissue* in the walls of the sacculus rotundus; *c,* the *ileo-colic aperture* and *valve.*

5. The *spiral valve* of the cæcum, and the *lymphoid tissue* of the vermiform appendix

6 The characters of the mucous membrane of the cæcum and large intestine

If it is intended that the rest of the dissection should be carried on another day, it will be best to stop here; then expose the thoracic viscera (for directions, see p. 535, D. 1) and wrap a cloth soaked in 3 per cent. formaline round the animal.

VII Ligature the postcaval at the points where it enters and leaves the liver: remove the entire liver, noting as you do so the *aorta, gullet, postcaval, hepatic veins,* and *phrenic veins.* Sketch the liver from the posterior surface. Then return to the examination of the abdomen, and make out (Fig. 167)—

1. The *renal* and *spermatic* (or *ovarian*) *arteries* and *veins.*

2. The *caudal artery,* arising from the dorsal side of the aorta

3. The *common iliac arteries,* each of which gives off an *ilio-lumbar* branch and divides into an *external* and an *internal iliac,* the former becoming continuous, beyond Poupart's ligament, with the *femoral.* (The course of these arteries and of the corresponding veins can be more easily traced after the urinogenital organs have been removed—see § IX.)

4 The *ilio-lumbar veins*, and the trifurcation of the post-caval into the *external iliacs* and a median vein formed by the fusion of the two *internal iliacs*.

Sketch all these vessels later, after the removal of the urinogenital organs

VIII. Dissect away the peritoneum and fat from the kidneys, ureters, and generative organs, and trace each ureter from the *hilus* of the kidney backwards to the bladder, which, if contracted, may be inflated from the urinogenital aperture. Then make out—

A. *In the male* (Figs 162 and 163) :—

1. The *penis*, with the *prepuce*, and the aperture of the *urinogenital canal* or *urethra*, which latter is lined by the soft *corpus spongiosum*, and strengthened by the *corpora cavernosa*, which diverge proximally and are attached to the ischia

2 The *scrotal sacs*, each communicating with the abdominal cavity by the *inguinal canal*, through which the corresponding *spermiduct* and the spermatic artery and vein pass to the *spermary*, to see which and the *epididymis* the scrotal sac should be slit open along its ventral wall

3 The course of the spermiducts

B *In the female* (Figs 165 and 166) .—

1. The *vulva*; and the *clitoris*, with its *corpora cavernosa*, on the ventral wall of the *urinogenital canal*

2. The *vagina*, *uteri*, and *uterine tubes* with their funnels.

3. The *ovaries*, studded with *ovarian follicles*

IX. Dissect away the kidneys, ureters—and in the male, the scrotal sacs, in the female, the ovaries—from the surrounding parts : cut through the pelvic symphysis with a knife, and sever the attachment of the corpora cavernosa to the ischia. Remove the whole of the urinogenital organs, together with the posterior end of the rectum, from the body and, after noting § VII, 3 and 4, pin them out in a dissecting-dish, with the ventral side uppermost, taking care to preserve the natural relations of the parts Dissect away all the superfluous connective-tissue and fat, separate the rectum at its cut end from the urinogenital canal, and turn it on one side, noting the *rectal* and *perineal glands*. Make out, in addition to the parts referred to in § VIII :—

A. In the male The *uterus masculinus* and *prostate*, and the *spermiducts* passing between the former and the bladder.

Sketch the entire dissection

Then slit open the uterus masculinus so as to see the openings of the spermiducts, remove the rectum and rectal glands, and make out the relations of the

corpus spongiosum Make a median incision along the whole length of the penis, beginning at the apex and cutting through the fibrous septum between the two corpora cavernosa: continue the incision forwards, so as to open the bladder along its ventral wall, and note and indicate on your sketch the openings of the ureters into the bladder, and the crescentic aperture of the uterus masculinus into the urinogenital canal, just at the anterior edge of a cushion-like fold

B. In the female. The wide *urinogenital canal* with its vascular walls.

Sketch the entire dissection.

Make a median longitudinal incision through the urinogenital canal, and continue it forwards until the cavity of the bladder is exposed; slit open the vagina and one of the uteri and uterine tubes in the same way Note and indicate on your sketch the openings of the ureters into the bladder, the connection of the neck of the bladder with the urinogenital canal, the large aperture in the latter leading into the vagina, and the thick-lipped aperture (*os uteri*) communicating between the vagina and thick-walled uterus, between which and its fellow is a vestigial septum, indicating the primarily paired character of the vagina Insert a seeker in the cœlomic aperture of the uterine tube. If your specimen is in an early stage of pregnancy, young embryos (*blastocysts*, p. 572) may be present in the uterine tubes, and should be carefully removed and fixed in corrosive sublimate (p. 144): if the uteri contains later embryos they present a series of swellings: cut one of the swellings open from the ventral side, and note the fœtus, enclosed by the *amnion* (p 593), and attached to a discoid *placenta* (p. 596); cut out the other swellings, together with their contents, and preserve them in formaline or alcohol.

With a scalpel or razor cut across one of the kidneys through the hilus, parallel to the dorsal and ventral faces of the organ, and note the *pelvis*, and its prolongations—the *calices*, the *urinary pyramid*, and the *cortical* and *medullary portions*. Sketch.

D. Dissection of the thorax and neck.

I. Dissect away the pectoral muscles, and open the thorax by a transverse incision just in front of the diaphragm; cut through all the ribs except the first along each side. Turn forward the ventral wall of the thorax as a triangular piece and carefully dissect it away from the underlying tissues at the anterior end, so as to detach it altogether

without injuring the jugular and brachial veins. Note in the *thoracic cavity* thus laid open :—

1. The *pericardium* and *heart*, and the *thymus* (Fig. 149).

2. The collapsed *lungs*. make a small aperture in the trachea and inflate

3. The *parietal* and *visceral layers* of the *pleura* and the *mediastinum* (Fig. 153).

4. The *pericardium* Cut the pericardium open longitudinally, noting the *pericardial fluid*.

II. Dissect away the pericardium, the thymus, and any fat about the base of the heart which may obscure the vessels arising from it. Follow out these vessels to the head by clearing away the connective-tissue, fat, &c., by which they are surrounded, but taking care not to injure any of the nerves of the neck (Fig 156). Make out :—

1. *a*, The *left* and *right ventricles* and *auricles*, and the ramifications of the *coronary artery* and *vein* ; *b*, the two *bronchi*.

2. *a*, The *pulmonary artery* and its division into left and right trunks ; *b*, the *pulmonary veins* (the course of which will be better seen at a later stage) ; *c*, the two *precaval veins*, each formed by the union of a *subclavian*, an *external jugular*, and a smaller *internal jugular*, *d*, the thoracic portion of the *postcaval vein*.

3. *a*, The *gullet* (cervical and thoracic portions) ; *b*, the *phrenic nerves* (p. 496) and the thoracic portions of the *vagi* (Fig. 156) ; *c*, the *arch of the aorta*, continuous with the *dorsal aorta*, and the short ligament (vestige of the fœtal *ductus arteriosus*) connecting the former with the pulmonary artery ; *d*, the thoracic portions of the *sympathetic nerves* and their *ganglia*, lying on the heads of the ribs ; *e*, the *azygos vein* (p. 487), best seen by turning the heart and lungs over to the left side of the animal The *thoracic duct* (p. 491) cannot easily be made out at this stage

4. *a*, The *innominate artery*, giving off the *left* and *right common carotids* and the *right subclavian* ; *b*, the *left subclavian artery* ; *c*, the division of each common carotid, at about the level of the anterior end of the larynx, into an *external* and an *internal carotid*.

Sketch the heart and origins of the main vessels.

III. Now dissect out certain of the nerves and other structures in the neck, as follows :—

1. The *vagus* (Fig. 156), running to the outer side of each common carotid : with the seeker carefully separate it from the carotid, and trace it forwards to the angle between the head and neck—at which point it enlarges to form a *ganglion*

—and backwards to the thorax. Branches are given off to the larynx (*anterior* and *posterior* or *recurrent laryngeal nerves*) and to the heart (*depressor*) nerves, but the dissection of these may be omitted by the beginner.

2. The *sympathetic* (Fig 156), running on the outer side of the carotid artery. This is readily seen by lifting up the carotid and carefully separating it from the vagus; traced forwards, it is seen to enlarge, at a level just anterior to the larynx, into the anterior *cervical sympathetic ganglion*, immediately external to which is a similar enlargement of the vagus, called the *vagus ganglion*: trace the sympathetic nerve from this ganglion backwards to the thorax, at the anterior end of which (close to the subclavian artery) it enlarges to form the *posterior cervical sympathetic ganglion*, and then becomes continuous with the thoracic portion of the cord.

3. The *hypoglossal nerve* will be seen at about the level of the vagus ganglion, crossing the vagus and sympathetic nerves and the carotid artery and passing forwards to the tongue.

4. Note—*a*, the *thyroid gland*; *b*, the *thyroid* and *cricoid cartilages* of the larynx; *c*, the *brachial* and *vertebral* branches of the subclavian artery; and *d*, the *brachial plexus* (p. 496)

IV. Remove the heart and lungs from the body, together with the posterior end of the trachea and recognisable portions of the aorta, precaval, and postcaval Fasten out the organs under water with their ventral surface uppermost, and after making out the course of the *pulmonary arteries* and *veins*, cut through them close to the lungs and separate the latter from the heart Note :—

1. The two *main lobes* of each lung and the two *accessory lobes* on the right side.

2. The *cartilages* of the *trachea* and *bronchi*; trace the bronchi for a short distance into the lungs. Sketch.

V. Dissection of the heart For the dissection of the heart, the heart of sheep can be substituted for that of the rabbit. Cut away the outer walls of both auricles so as to expose their cavities, taking care not to injure the veins which enter them. Wash out the contained clots of blood, and note—

1. *a*, The *appendix* of each auricle, and the network of muscular bands in its walls; *b*, the *septum auricularum* and *fossa ovalis* (Fig 154)—best seen from the left side by holding the heart between your eyes and the light.

2. *a*, The *auriculo-ventricular apertures*; *b*, the *apertures*

of the *precaval* and *postcaval veins*; *c*, the *Eustachian valve*; *d*, the aperture of the *coronary vein* within the tunnel-like opening of the left precaval; *e*, the apertures of the *pulmonary veins*.

Then cut away both auricles so as to expose the bases of the ventricles, and remove all but about an eighth of an inch of the aorta and pulmonary artery; pour water into the ventricles through the auriculo-ventricular apertures and squeeze the ventricles, noting—

3. *a*, The *bicuspid* and *tricuspid* valves, and the *semilunar valves* at the origins of the aorta and pulmonary artery respectively; *b*, the apertures of the *coronary arteries* just distally to the aortic valves.

Sketch

Now remove the outer walls of both ventricles by making first a transverse incision along the base of each, and then, from its extremities, converging incisions nearly to the apex of the heart. Make out:—

4. The relative thickness of the walls of the right and left ventricles, the form of the *septum ventriculorum*, the cavities of the two ventricles, and the muscular ridges in their walls.

5 The flaps of the *tricuspid* and *bicuspid valves* and their *tendinous cords* and *papillary muscles* (Fig 154).

6 The apertures of the aorta and pulmonary artery into the left and right ventricle respectively.

Sketch.

E **Dissection of the head.**

(For want of time, the elementary student can omit I and II under this section, only examining the more important structures in the mouth-cavity and the cartilages of the larynx)

I. Carefully dissect the skin away from one side of the head; either side will do, but if you are using the head from which you have already removed the brain, choose the side on which the auditory region is least damaged: notice the *Meibomian glands* (p. 500). Cut away, with bone-forceps, the supraorbital process of the frontal, being careful not to injure any of the contents of the orbit. Note—

1. *a*, A large mass of muscle (*masseter*) covering the posterior half of the mandible, on which branches of the *facial nerve* will be seen; *b*, the thin irregular *parotid* gland, at the base of the pinna, and the large *infraorbital gland* lying mainly within the orbit below (p. 474).

2. The four *recti* and the two *oblique muscles* of the eye. Note the course of the superior oblique through its tendinous loop (p. 500).

3 The *lacrymal* and *Harderian* glands, situated in the postero-superior and antero-inferior regions of the orbit respectively.

II. Remove the eyeball by cutting through the muscles and optic nerve, noting the *retractor bulbi* muscle around the latter. (For the dissection of the eye, see p. 541). Cut off the pinna, and clear away the muscles, &c., covering the tympanic bone: remove the entire tympanic and periotic bones (p 449) in one piece, lay open the external auditory passage, and very carefully and gradually cut away the outer wall of both tubular and bulbous portions of the tympanic with the bone-forceps. Note:—

1. The *tympanic membrane* and the handle of the *malleus;* and after cutting away the former so as not to injure the latter, and removing rather more of the bulla, make out (Fig 161)—

2. The *tympanic cavity*, the *malleus*, *incus*, and *stapes;* the *tensor tympani* and *stapedius muscles;* and the aperture of the *Eustachian tube.* Remove the auditory ossicles, noting as you do so the *fenestra ovalis* and *fenestra rotunda*, and examine them under the low power of the microscope: by cutting through the periotic with the bone-forceps, the position of the *membranous labyrinth*, including the *cochlea*, may be made out.

III. Dissect off the muscles covering the mandible on the side you are working; detach its ascending portion from the muscles inserted on its inner surface, remove it entire, cutting through the symphysis, and clear away the underlying muscles Pass a probe from the cut end of the gullet forwards into the mouth: lay open the gullet along this, and pull the tongue downwards, so as to get a view into the interior of the mouth (Fig. 149). Note:—

1. *a*, The *palate* and *velum palati; b*, the *tongue* and its *papillæ* (p 471); *c*, the *pharynx; d*, the *glottis* and *epiglottis; e*, the continuation of the pharynx above the velum palati (*nasopharynx*), with which the internal nostrils communicate; *f*, the positions of the *teeth* (incisors and grinders); *g*, the apertures of the *naso-palatine canals.*

With a fine saw, make a longitudinal vertical section of the entire head, cutting very slightly to that side of the median line on which you are working, so as not to injure the cartilaginous *nasal septum.* Pin down and finish dissecting under water, noting again the parts just referred to (§ 1) and also—

2 The *cranial cavity*, the roof of which will have been cut away if the brain has been removed.

3. The *aperture* of the *Eustachian tube* · pass a probe from it into the tympanic cavity

4. The position of *Jacobson's organ*, on the ventral side of the nasal septum ; and after cutting away the latter, the *olfactory nerve*, *ethmo-turbinal*, *maxillo-turbinal*, and *naso-turbinal* of the other side (p. 451, Fig 139).

Sketch the entire longitudinal section

IV. Remove the larynx with the anterior part of the trachea Make a longitudinal vertical section of it, keep one half entire, and from the other dissect away the muscles and mucous membrane so as to see the cartilages clearly. Examine first the cartilages and then the soft parts, noting the relations of the *thyroid*, *cricoid*, and *arytenoid cartilages*, the *epiglottis* and the *vocal cords* (p. 479) Sketch.

F. Dissection of typical flexor and extensor muscles and joints of the fore-limb.

1. Expose the *biceps* (chief *flexor* of the fore-arm). Its *origin* is from the anterior edge of the glenoid cavity on the pectoral arch : it arises by a single long *tendon*, working in the bicipital groove of the humerus. It is spindle-shaped, consisting of a single *belly*, and is *inserted* on the proximal end of the radius.

2. Expose the *triceps* (chief *extensor* of the fore-arm) It arises by three main heads from the pectoral arch and humerus, and is inserted on the olecranon-process of the ulna

3. Remove the muscles from the shoulder-joint, and note the *capsular ligament* (p. 58) Cut through this so as to open the *synovial capsule*, and note the *synovial membrane* and *fluid* and the cartilaginous *articular surfaces* of the glenoid cavity and head of the humerus respectively . or, prepare as directed on p 67 in the case of the hip-joint of the frog.

G. The Brain.

(The brain should be examined and dissected about a fortnight after its removal from the body, by which time it will be sufficiently hardened, as the result of having been kept in spirit)

I. External characters Note (Fig. 158) :—

1. The *medulla oblongata*, with its dorsal and ventral fissures and the *pons Varolii ;* the convoluted *cerebellum*, consisting of a *central lobe* and two *lateral lobes* and *flocculi*.

2. The *optic lobes*, seen on slightly separating the hemispheres and cerebellum ; the *crura cerebri*

3. The *olfactory lobes*; the *cerebral hemispheres* (*frontal, parietal*, and *temporal lobes*)—by gently separating them, the *corpus callosum* will be seen, and just behind them the *pineal body*; the *diencephalon* is covered above by the hemispheres, below it is visible and is continued into the *infundibulum*; the *pituitary body* is nearly always left behind in the brain-case when the brain is removed, and a small aperture is seen in the centre of the infundibulum where it was attached; the *optic chiasma*

4. The origins of the nerves from the brain; these cannot, of course, be plainly made out unless the nerves have been carefully cut through when removing the brain. Compare pp. 172-175, and note in addition the *spinal accessory* and *hypoglossal*.

Sketch the brain from above and from below.

II Carefully remove successive slices from one of the hemispheres nearly parallel to its upper surface, down to the level of the corpus callosum, noting the fibres of the latter and the relations of the grey and white matter in the hemispheres. Cut through the corpus callosum longitudinally, near the middle line, and remove sufficient of the hemisphere already dissected to expose the *lateral ventricle* and its extensions into the frontal, parietal, and temporal lobes Note:—

1. The *hippocampus*, the *corpus striatum*, the *choroid plexus*, and the *septum lucidum* (p 495) Then cut away the rest of the same hemisphere so as to expose—

2. *a*, The *diencephalon* and its two lateral halves (*optic thalami*) between which the *third ventricle* is enclosed; from its roof the stalk of the pineal body arises; *b*, the two pairs of *optic lobes*. Cut away the lateral half of the cerebellum of the same side, and note—

3 The *valve* of *Vieussens*, the *fourth ventricle*, and the tree-like appearance (*arbor vitæ*) of the cerebellum in section.

III. Now reduce the whole brain to a longitudinal vertical section (Fig 159), cutting it through with a sharp knife very slightly to that side of the median line which you have already dissected, so as to expose the median ventricles in section. Make out, on the uninjured half, the relations of the *third ventricle, iter, fourth ventricle, foramen of Monro, infundibulum, optic chiasma, corpus callosum* and *fornix, lamina terminalis, anterior, middle*, and *posterior commissure, crura cerebri, valve of Vieussens, pons Varolii, &c.* Sketch.

H. **The Eye.**

On account of its larger size, it is better to substitute the eye of a sheep—which can be obtained fresh from a

butcher—for that of the rabbit. Two specimens should be obtained, and the fat, muscles, and any portions of the eyelids remaining attached cleared away. Dissect under water.

1. After noting the *conjunctiva*, *cornea*, *sclerotic*, *optic nerve*, *iris*, and *pupil*, insert the scissors near the margin of the cornea, and cut all round the cornea, with stout scissors, about one-eighth of an inch in front of its junction with the sclerotic, taking great care to hold the eyeball lightly in your fingers so as not to squeeze it, as otherwise not only the aqueous humour but also the lens are driven out. Remove the circular piece of cornea thus cut off, so as to expose the *aqueous chamber*, noting the *aqueous humour*, as well as the *iris*, *lens*, and *pupil* (compare Fig. 63). Sketch.

Insert the point of the scalpel under the cut edge of the cornea between it and the iris, and by working it all round separate off the sclerotic from the choroid, in the outer half of the eyeball Make four radial cuts, through the margin of the cornea and the sclerotic, at equal distances from one another, extending the cuts back towards the optic nerve. Turn back the four flaps thus made, and insert pins through them so as to fix the eye firmly down under water with the iris uppermost: note the *ciliary muscle* around the outer margin of the iris, the *choroid*, and the *ciliary vessels* and *nerves*. Then make four radial cuts, at equal distances from one another, through the iris and choroid, and turn back the portion between the cuts, noting the radially arranged *ciliary processes* on the hinder surface of the outer margin of the iris, the iridescent *tapetum* of the back portion of the choroid, the outer surface of the *retina*, extending forwards up to the region of the indentations left on the capsule of the lens by the ciliary processes (the wavy anterior margin of the retinal cup being known as the *ora serrata*), and the *lens* with its capsule On now reflecting a portion of the retina, its inner surface with its blood-vessels, the *blind spot* (or point of entrance of the optic nerve), and the gelatinous vitreous humour filling the posterior chamber of the eyeball will be seen Sketch, showing the various parts as they actually lie in your dissection. Remove the lens from its capsule and notice the curvature of its anterior and posterior surfaces.

2. Cut your second specimen into vertical halves with the scissors, making the cut pass through the cornea, pupil, and optic nerve. As it is difficult to cut through the lens without disturbing its relations, it should be carefully separated from one half, and left entire on the other half.

Examine the relations of the parts once more, compare Fig. 160, and sketch.

I. **Microscope preparations.**

Besides the histological preparations already studied from the Frog, the student would do well to examine the following preparations from the Rabbit or some other mammal.

(*a*) *The skin.* Examine a prepared transverse section through the *hairs*, *hair-sacs*, *sebaceous glands*, and *sweat glands* (compare p. 442).

(*b*) *The blood* Examine a drop of blood obtained from a freshly killed rabbit, or by pricking the tip of your finger Put the drop near one end of a glass slide, and holding obliquely another slide over it so as to enclose a small angle with the drop of blood between the two, draw the second slide along the surface of the first, so as to spread the blood into a thin, even film Gently heat the slide with the film side upwards, over the flame of a spirit lamp, so as to fix the film. Note that the red *corpuscles* are circular, biconcave, non-nucleated, and of a considerably smaller size (about $\frac{1}{3200}$ inch or 0·008 mm. in diameter) than those of Frogs' blood. The *white corpuscles*, which are fewer in number (1 to 500 or 600 of the red), and larger in size than the red, irregular in shape and nucleated, will also be recognised (see p. 491).

In a properly prepared and stained film of blood, the white corpuscles are seen in a variety of forms, and their structure can be best determined in such preparations

(*c*) Prepared transverse and longitudinal sections of *bone* should be examined, and the concentric arrangement of lamellæ, Haversian canals, lacunæ, and canaliculi noted (compare p. 124)

(*d*) Microscopic sections of the *small intestine*—injected and uninjected—should also be examined, compared with Fig. 44, and the *villi* and *intestinal glands* noted.

(*e*) Examine microscopic preparations of injected and uninjected *kidney* (compare pp. 153 and 503)

(*f*) Microscopic sections of the *ovary* should be examined, and the hollow *ovarian follicles* noted, each consisting of follicular *cells* enclosing a minute *ovum* (compare p. 506).

CHAPTER X

THE MINUTE STRUCTURE OF CELLS: CELL-DIVISION: STRUCTURE OF THE OVUM: GAMETOGENESIS (SPERMATOGENESIS AND OOGENESIS): MATURATION AND FERTILISATION OF THE OVUM: DIFFERENT TYPES OF OVA AND OF SEGMENTATION—EFFECT OF FOOD-YOLK ON DEVELOPMENT

Structure of the Cell.—We have learnt in previous chapters that all organisms are formed essentially of one or more *cells* (compare *e.g.* pp. 116 and 125); that the cell consists of *protoplasm*, and contains a *nucleus*, enclosing *chromatin* and usually one or more *nucleoli* (p. 115); and that cells multiply by a process of *binary fission* (pp. 112, 248). It will now be necessary to study the structure of a typical animal-cell and of its mode of division in somewhat greater detail.

There seems to be a good deal of variation in the precise structure of various animal- and plant-cells. In the cell-body or *cytoplasm* two constituents may be distinguished—a clear semi-fluid substance, traversed by a delicate sponge-work. Under the microscope the whole cell is not seen at once, but only an *optical section* of it—that is, all the parts which are in focus at one time (see *e.g.* Fig. 76, B): by altering the focus we view the object

at successive depths, each view being practically a slice parallel to the surface of the lenses. This being the case, protoplasm presents the microscopic appearance of a clear or slightly granular matrix traversed by a delicate network (Fig. 178). In the epithelial cells of animals the protoplasm is bounded externally by a very delicate *cell-membrane*: in amœboid cells the ectoplasm, or transparent, non-granular portion of the cell, consists

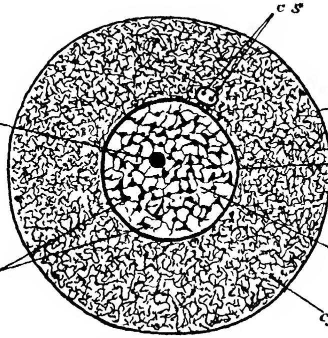


FIG 178.—Diagram of a typical cell
ch g chromatin granules, *c m* cell-membrane, *c s* centrosomes lying in centro sphere; *cyt* cytoplasm, *n m* nuclear membrane; *nu* nucleus, *nucl* nucleolus (From Dendy's *Outlines of Evolutionary Biology*)

of clear protoplasm only, the granular endoplasm alone possessing the sponge-work.

It is quite possible that the reticular character of the cell may be merely the optical expression of an extensive but minute vacuolation, or may be due to the presence of innumerable minute granules developed in the protoplasm as products of metabolism.

The nucleus is spherical or oval in form, and is enclosed in a delicate *nuclear membrane* (Figs. 178 and 179, A). Its contents (*nucleoplasm*) consist of a homogeneous semi-fluid substance throughout which an extremely

fine network of threads extends. this is called the *linin* network, and in it are embedded granules of *chromatin* (*ch. g*, *chr*), which are distinguished by their strong affinity for aniline and other dyes (compare *e.g.* Part I, Chaps. VII and VIII). Frequently, as we have seen, one or more minute globular structures, the *nucleoli* (*nucl*, *kk*), occur in the nucleus: they also have a strong affinity for dyes although often differing considerably from the chromatin in their micro-chemical reactions

Close to the nucleus a small globular body, called the *centrosphere* (*csph*), enclosing a minute particle or *centrosome*, is present in the cell; it is inconspicuous and often difficult to recognise, but probably occurs in all animal-cells which are capable of division.

Cell-division.—The precise changes which take place during the fission of a cell are, like the structure of the cell itself, subject to considerable variation. We will consider what may probably be taken as a typical case (Fig. 179).

First of all, the chromatin granules (*chr*) come together so as to form a loose coil or skein, the *spireme* (B). The centrosome and then the centrosphere (*csph*) divide, and from the latter fine cytoplasmic filaments are seen to radiate; the products of its division gradually separate from one another (C), ultimately passing to opposite poles of the nucleus (D), delicate protoplasmic threads extending from one to the other in the form of a *spindle* (*ksp*). At the same time, the nuclear membrane and the nucleoli usually disappear, and the chromatin skein divides into a number of separate pieces of equal length called *chromosomes* (C, *chrs*), the form of which varies in different cases: they may be spherical, rod-shaped, or V-shaped, and, in general, their number is constant in

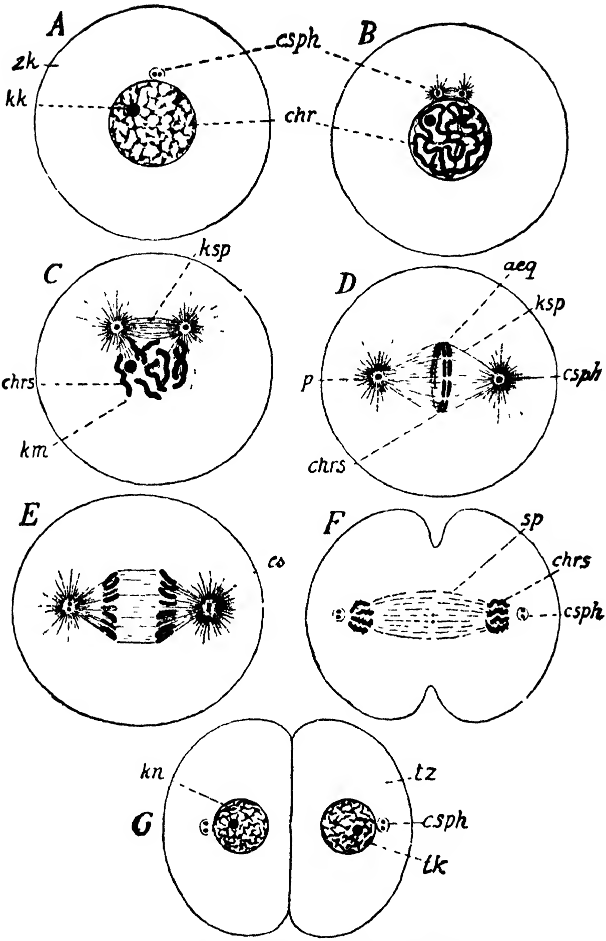


FIG 179 —Diagram of nuclear division

A, resting-cell, with cytoplasm (*sk*), centrosphere (*csph*) which contains two centrosomes, nucleolus (*kk*) and chromatin (*chr*), the last distributed in the linin network, the whole nucleus is surrounded by a nuclear membrane *B*, the chromatin united in a coiled thread, the centrosphere divided into two and giving off rays which unite the two *C*, the nuclear spindle (*ksp*) formed, the rays more strongly developed, the nuclear membrane (*km*) in process of dissolution, the chromatin thread divided into eight similar chromosomes (*chrs*), the rays becoming attached to the chromosomes *D*, perfected nuclear spindle with

the two centrospheres at the poles (*csph*) and the eight chromosomes (*chrs*) in the equator of the spindle, all now longitudinally split. *E*, daughter chromosomes diverging from one another, but still united by filaments, the centrosomes (*cs*) are already doubled for the next division. *F*, daughter chromosomes, quite separated from one another, are already beginning to give off processes, only the four of one aspect of the spindle being indicated, the cell-body is beginning to be constricted *G*, end of the process of division, two daughter-cells (*tz*) with similar nuclear network (*tk*) and centrospheres (*csph*) as in *A*. (From Weismann's *Evolution Theory*, adapted from E B Wilson)

any given species of animal or plant, although it may vary in different species from two to a hundred and eighty-six or more.

The chromosomes become arranged in the equatorial plane of the spindle and each of them splits along its whole length, so as to form two parallel rods or loops in close contact with one another (D), and arranged in a radiating manner so as to present a star-like figure or *aster* when the cell is viewed in the direction of the long axis of the spindle · in this way the number of chromosomes is doubled, each one being represented by a pair. Everything is now ready for division, to which all the foregoing processes are preparatory.

The two chromosomes of each pair now gradually pass to opposite poles of the spindle (E), two distinct groups being thus produced and each chromosome of each group being the twin of one in the other group. The mechanism by means of which this is effected is not definitely known: possibly the fibres of the spindle are the active agents in the process, the chromosomes being dragged in opposite directions by their contraction: on the other hand, it is possible that the centrosomes may possess an attractive force, or that the movement is due to the contractility of the chromosomes themselves.

After reaching the poles of the spindle (F) the chromosomes of each group unite with one another to form a network around which a nuclear membrane finally makes its appearance (G). In this way two nuclei are produced within a single cell, the chromosomes of the *daughter-*

nuclei, as well as their attendant centrosomes, being formed by the binary fission of those of the *mother-nucleus*.

But *pari passu* with the process of nuclear division, fission of the cell-body is also going on. This takes place by a simple process of constriction (F, G)—in much the same way as a lump of clay or dough would divide if a loop of string were tied round its middle and then tightened.

In comparatively few cases the dividing nucleus instead of going through the complicated processes just described divides by simple constriction, but this seems to occur only in the case of certain highly differentiated cells or of worn-out cells. We have therefore to distinguish between *direct* and *indirect nuclear division* [1]

From what we have now learnt in this chapter as well as in previous ones about the nucleus (compare *e g.* p. 248) and its complicated mode of division, we conclude that it is of prime importance in regulating the life and determining the characters of the cell, and that the chromatin is probably the substance on which these characters depend.

In this connection the reader will not fail to note the extreme complexity of structure revealed in cells and their nuclei by the highest powers of the microscope. When the constituent cells of the higher animals and plants were discovered, during the early years of last century, by Schleiden and Schwann, they were looked upon as the *ultima Thule* of microscopic analysis. Now the demonstration of the cells themselves is an easy matter, the problem is to make out their ultimate constitution. What would be the result if we could get microscopes as superior to those of to-day as those of to-day are to the primitive instruments of a hundred years ago, it is impossible even to conjecture.

[1] To the latter very elaborate method the name *mitosis* or *karyokinesis* is applied : direct division is then distinguished as *amitosis*.

Structure of the Ovum.—The striking general resemblance between the cells of the higher animals and entire unicellular organisms has been commented on as a very remarkable fact: there is another equally significant circumstance to which we must give our attention.

All the higher animals begin life as an egg, which is either passed out of the body of the parent, as such, as in earthworms, insects, frogs, birds, &c. (*oviparous forms*), or undergoes development in the body of the parent, as in some dogfishes and nearly all mammals (*viviparous forms*).

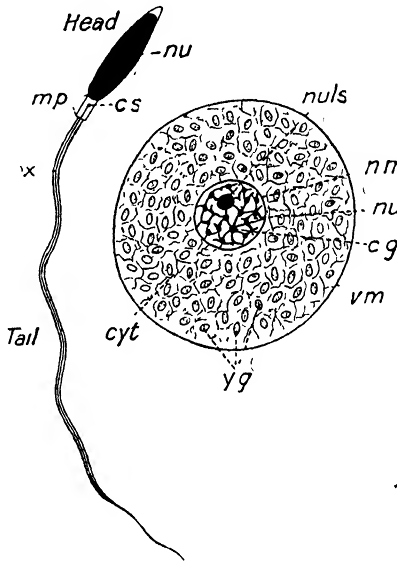


FIG. 180.—Diagram of typical sperm and ovum, the former much more magnified than the latter *ax.* filament; *cg* chromatin granules, *cs* centrosome; *cyt* cytoplasm, *mp* middle piece, *nm* nuclear membrane; *nu* nucleus, *nuls.* nucleolus; *vm.* vitelline membrane, *yg* yolk-granules. (From Dendy)

The structure of an egg is, in essential respects, the same in all animals from the highest to the lowest (compare p. 206). It consists (Fig. 180) of a more or less globular mass of protoplasm (*cyt*), spoken of as the *vitellus*, in which are deposited proteinaceous particles known as *yolk-granules* (*y.g*). Within the protoplasm is a large nucleus containing chromatin as well as one or more nucleoli (*nu, nuls*)—which are often known

as *germinal spots*, the entire nucleus of the ovum being sometimes called the *germinal vesicle*. In other words the egg, as we have already seen, is a cell. An investing *vitelline membrane* (*v m*) is usually present, though often only formed after fertilisation.

The young or immature ova of all animals present this structure, but in many cases certain modifications are undergone before the egg is fully formed. For

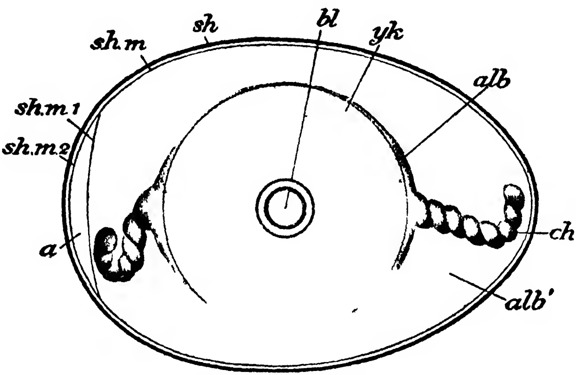


FIG. 181.—Semi diagrammatic view of the egg of the Fowl at the beginning of incubation (Nat size)
a, air-space, *alb* dense layer of albumen, *alb'* more fluid albumen; *bl* blastoderm; *ch* chalaza, a twisted cord of the dense layer of albumen at either end of the egg, formed as the latter rotates down the oviduct, *sh* shell, *sh m* shell membrane, *sh m* 1, *sh m* 2, its two layers separated and enclosing air-cavity (From Parker and Haswell's *Zoology*, after Marshall, slightly altered)

instance, the protoplasm may throw out pseudopods, the egg becoming amœboid (p. 305); or, as mentioned above, an investing membrane may be secreted by the egg, or by the follicular cells: this is often of considerable thickness, and may be perforated at one pole by an aperture, the *micropyle* (Fig. 183. B, C). The most extraordinary modification takes place in some Vertebrata, such as dogfishes and birds. In a hen's egg, for instance (Fig. 181), the yolk-granules

increase immensely, swelling out the microscopic ovum until it becomes what we know as the "yolk" of the egg: around this layers of albumen or "white" are deposited by the glands of the oviduct, and finally the double shell-membrane and the shell. Hence we have to distinguish carefully in eggs of this character between the entire "egg" in the ordinary acceptation of the term, and the ovum or egg-cell. But complexities of this sort do not alter the fundamental fact that all the higher animals begin life as a single cell; or in other words, that multicellular animals, however large and complex they may be in their adult condition, originate as unicellular bodies of microscopic size; and the same is the case with plants.

Gametogenesis (Spermatogenesis and Oogenesis).—In the preceding chapters it has more than once been stated that sperms arise from undifferentiated epithelial cells in the spermary, and that ova are produced by the enlargement of similar cells in the ovary. Fertilisation has also been described as the conjugation of two different kinds of gametes, the ovum and sperm (compare p. 209). We have now to consider in greater detail what is known as to the precise mode of development of sperms (*spermatogenesis*) and of ova (*oogenesis*), as well as the exact steps of the process by which an oosperm or unicellular embryo is formed by the union of the two sexual elements.

Both ovary and spermary are at first composed of cells of the ordinary kind, the *primitive germ-* or *sex-cells*; and it is only by the further development of these that the sex is determined.

In the spermary the sex-cells (Fig. 182, A) undergo repeated fission, forming what may be called the *sperm-mother-cells* (B) or *male gametocytes* (pp. 206 and 305).

In these, as well as in the egg-mother-cells (p. 207), the nucleus, instead of dividing in the ordinary way, as described on p. 546, undergoes a special kind of division.

We saw that the number of chromosomes is in general

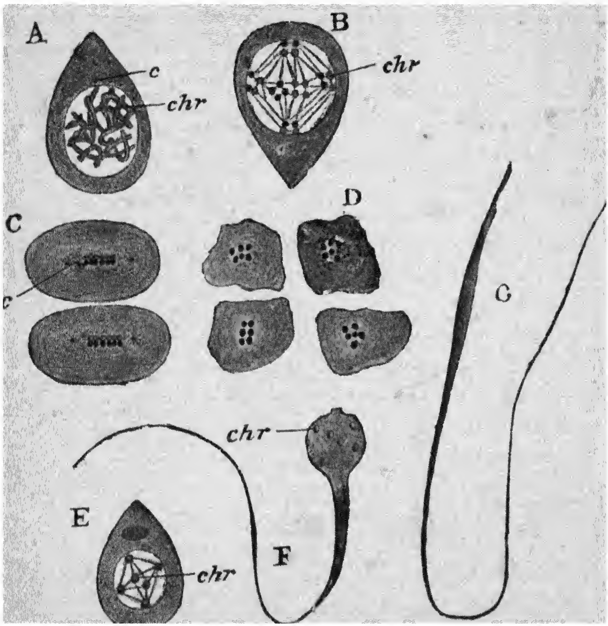


FIG. 162 —Spermatogenesis in the Mole-cricket (*Gryllotalpa*)
A, primitive sex-cell, just preparatory to division, showing twelve chromosomes arranged in tetrads (*chr*), *c* the centrosome. B, sperm-mother-cell, formed by the division of A, and containing twenty-four chromosomes arranged in tetrads, the centrosome has divided into two C, the sperm-mother-cell has divided into two, each daughter-cell containing twelve chromosomes. D, each daughter-cell has divided again, a group of four sperm-cells being produced, each with only six chromosomes. E, a single sperm-cell about to elongate to form a sperm F, immature sperm, the six chromosomes are still visible in the head G, fully formed sperm (From Parker's *Biology*, after vom Rath)

constant in any given animal, though varying greatly in different species. Now in the nucleus of the sperm-mother-cells the chromosomes become applied close

together in pairs, and the two members of each pair undergo longitudinal division, so that a group of four (*tetrad*) is formed from each pair. Thus, supposing the number of chromosomes in the ordinary cells of the body, including the primitive sex-cells, to be twelve (Fig. 182, A), there will be six groups, each containing four chromosomes, *i e.*, twenty-four in all, or double the number characteristic of the species (B). As the spindle is formed, these tetrads become arranged on its equator, two chromosomes from each group then passing to one pole and two to the other. The cell now divides, and the nucleus of each daughter-cell thus contains twelve chromosomes (C). The process of division, without a return to the spireme stage (p. 546), is then repeated in each; but the chromosomes this time do not split longitudinally, six of them passing entire to each pole of the spindle respectively. Cell-division follows, and it will be seen that each of the four cells derived from the original mother-cells contains only six chromosomes (D), *i.e.* half the normal number, and the process is therefore known as a *reducing division*. The four cells thus produced are the immature sperms (E): in the majority of cases the protoplasm of each undergoes a great elongation, being converted into a long vibratile thread, the *tail* of the sperm (F, G), while the nucleus constitutes its more or less spindle-shaped *head* and the centrosome is included in a small *middle piece* at the junction of head and tail (Fig. 180).

Thus the sperm or male gamete is a true cell specially modified in most cases for active movement. This actively motile, tailed form is, however, by no means essential: in some animals (*e.g.* arthropods) the sperms are non-motile and of peculiar form.

The ova arise from primitive sex-cells, precisely resembling those which give rise to sperms. They

divide and give rise to the *egg-mother-cells*, or *female gametocytes*, which do not immediately undergo division, but remain passive and increase in size by the absorption of nutriment from surrounding parts: in this way each egg-mother-cell gives rise to an *ovum*. Sometimes this nutriment is simply taken in by diffusion or osmosis, or by means of protoplasmic connection between the ovum and the follicle-cells; in other cases the growing ovum actually ingests neighbouring cells after the manner of an Amœba. Thus in the developing egg the processes of constructive are vastly in excess of those of destructive metabolism.

We have seen (p. 253) that the products of destructive metabolism may take the form either of waste products which are got rid of, or of plastic products which are stored up as an integral part of the organism. In the developing egg, in addition to the increase in the bulk of the protoplasm itself, a formation of plastic products usually goes on to an immense extent. In plants the stored-up materials may take the form of starch, of oil, or of protein substance: in animals it consists, as mentioned above, of rounded or angular grains of protein material, known as yolk-granules. These being deposited in the protoplasm, like plums in a pudding, have the effect of rendering the fully-formed egg opaque, so that its structure can often be made out only in sections.

Before, however, the ovum is ripe for conjugation with a sperm or able to undergo the first stages of segmentation it has to go through a process known as *maturation*, which consists essentially in a twice repeated process of cell-division, and thus resembles the process just described in the case of the sperms.

Let us take a case, as before, in which the number of chromosomes characteristic of the species is six.

These, in the egg-mother-cells, become arranged in pairs. The nucleus loses its membrane, travels to the surface of the egg, and a spindle is formed. Next the protoplasm grows out into a small projection or bud, into which one end of the spindle projects (Fig. 183). Nuclear division takes place, without a splitting of the chromosomes, one of the daughter nuclei remaining in the bud, the other in the ovum itself, each of these nuclei containing three chromosomes. Then follows, as usual, a division of the protoplasm, and the bud becomes separated as a small cell distinguished as the *first polar cell or body.*

In some cases development from an unfertilised female gamete takes place, the process—which occurs in various invertebrate groups and is not uncommon during a greater part of the year among insects (*e g.* the common little green plant-louse or *Aphis*) and crustaceans (*e g.* water-fleas)—being distinguished as *parthenogenesis* It has been shown that in many such cases the egg begins to develop after the formation of the first polar cell, when the ovum in these cases still contains the number of chromosomes normal to the species.

As a general rule, development takes place only after fertilisation, and a *second polar cell or body* (Fig. 183) is formed from the ovum, a longitudinal division occurring as usual, so that the ovum and the second polar cell each contain only three chromosomes, that is, half the number found in the nucleus of the egg-mother-cell, and in the nuclei of the cells of the body in the particular species. Thus the ovum has now lost a portion of its protoplasm together with some of its chromatin, some having passed into the first polar cell and half of what remained into the second: the remaining portion of the chromatin becomes enclosed in a nucleus which is distinguished as the *female pronucleus* (Fig. 184 *no.*)

The first polar body has in many cases been observed to divide after separating from the egg, so that the

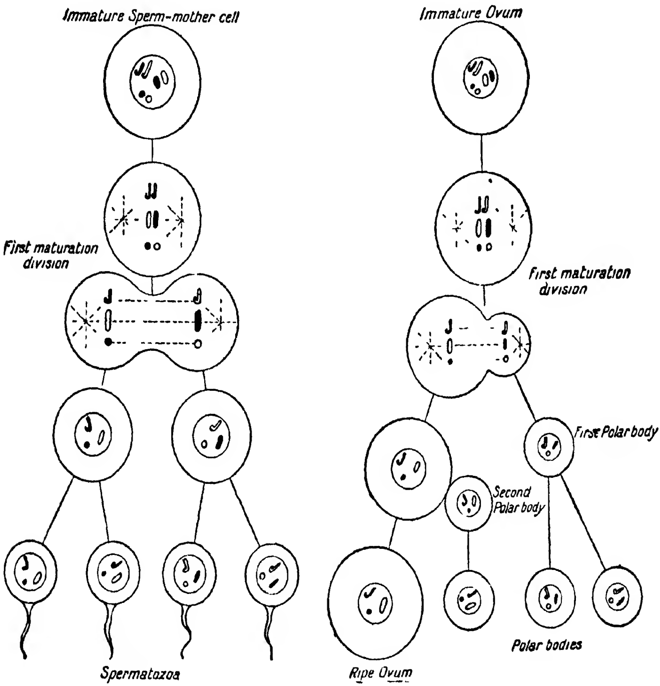


FIG 183 —Diagrams illustrating the maturation divisions of germ cells leading to formation of four gametes, each with half the number of chromosomes found in the body cells On the left formation of four spermatozoa, and on the right of one ripe ovum and three polar bodies in a Metazoon The separation of the chromosomes and the consequent halving of their number takes place usually in the first maturation division Paternal chromosomes are represented black, maternal chromosomes white As the result of the maturation divisions, not only are the number of chromosomes halved, but each gamete contains some chromosomes originally derived from the male parent and some from the female parent of the individual producing the gametes (After Goodrich, Oxford University Press.)

egg-mother-cell or immature ovum gives rise to a group of four cells—the mature ovum, and three abortive

ova or polar cells which develop no further,[1] just as the sperm-mother-cell gives rise to a group of four cells, all of which, however, become sperms (Fig. 182).

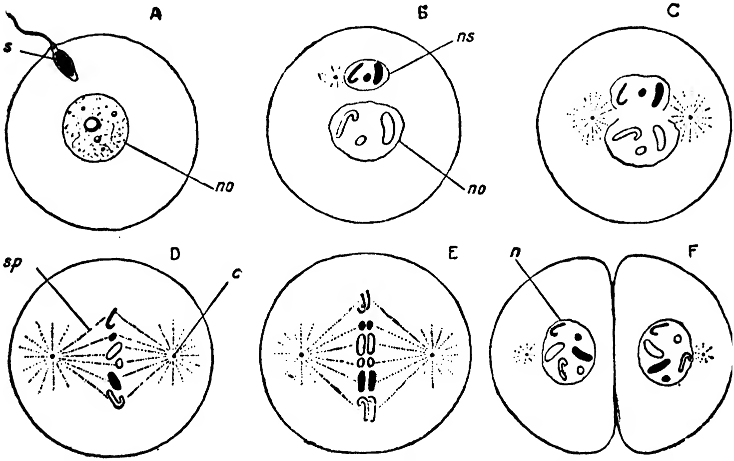


FIG 184 —Diagrams of the fertilisation and first segmentation division of the zygote in a Metazoon A, entrance of spermatozoon B, appearance of chromosomes in male and female pronuclei, centrosome brought in by the spermatozoon C, division of centrosome, disappearance of nuclear membrane and fusion of nuclei D, chromosomes set on equatorical plane of spindle E, division of chromosomes which pass to opposite ends of spindle F, reconstitution of two daughter nuclei and division of zygote into two cells Paternal chromosomes represented black, maternal chromosomes white *c*, centrosome; *no*, daughter nucleus of ovum or female pronucleus, *ns*, nucleus of spermatozoon or male pronucleus, *s*, spermatozoon, *sp*, achromatic spindle (After Goodrich, Oxford University Press)

Fertilisation of the Ovum.—Shortly after maturation,[2] the ovum is fertilised by the conjugation with it of a

[1] It will be remembered that there is an analogous casting off of nuclear material in the process of conjugation in *Paramecium* (p 263).

[2] In the case of most animals in which the formation of polar bodies has been observed, fertilisation is effected only after the first and second polar cells are extruded. In the frog, the extrusion of the second polar cell occurs only after the spermatozoon has entered the egg, though before the act of fertilisation is completed.

single sperm. As we have found repeatedly, sperms are produced in vastly greater numbers than ova, and it often happens that a single egg is seen quite surrounded with sperms, all apparently about to conjugate with it. It has, however, been found to be a general rule that only one of these actually conjugates: the others, like the drones in a hive, perish without fulfilling the one function they are fitted to perform.

The successful sperm takes up a position at right angles to the surface of the egg and gradually works its way into the ovum, passing through the micropyle when present, until its head lies within the egg-protoplasm. The tail is then lost, and the head, accompanied by the centrosome (see p. 554 and Fig. 180), penetrating deeper into the protoplasm, takes the form of a rounded body, the *male pronucleus*. The centrosome of the ovum disappears, that of the sperm dividing subsequently.

The two pronuclei approach one another (Fig. 184, B) and finally unite to form what is called the *segmentation-nucleus* (E, *seg. nucl*), the single nucleus of what is not now the *ovum* but the *oosperm*—the impregnated egg or the starting point of a new individual (compare p. 209).

The fertilising process is thus seen to consist essentially in the intermingling in equal proportions of chromatin-material derived from two conjugating cells or gametes, and the term is often restricted to those cases of conjugation in which the gametes differ from one another, so that one can distinguish between a male gamete and a female gamete, known in the Metazoa as a sperm and an ovum respectively. It follows from what has been said above that the essential nuclear matter or chromatin of the oosperm—often spoken of as the *germ-plasm* and probably constituting the material basis of heredity—is

derived in equal proportions from each of the two parents. Moreover, as both male and female pronuclei contain only half the number of chromosomes found in the ordinary cells of the species, the union of the pronuclei results in the restoration of the normal number to the oosperm; and as the reducing divisions and conjugation of the germ-cells thus apparently render possible very varied permutations and combinations of the hereditary qualities of both sexes, these processes seem to have a great importance in connection with the phenomenon of individual variation (p. 228).

Fertilisation being thus effected, the process of *segmentation* or division of the oosperm takes place as described in previous chapters.

Different Types of Ova and of Segmentation.—Before passing on to consider further details in the process of development of the oosperm, we must briefly refer to some differences already noted in the ova of different animals.

We have seen that in all cases the immature egg is a simple, minute cell, but that, owing to the deposition of yolk-granules in its protoplasm, it may reach a comparatively large size (*e.g.* dogfish, bird). The presence of a greater or less amount of yolk in the ovum results, as we know, in very considerable differences as regards its mode of segmentation, as well as in its subsequent development. The minute eggs of the amphioxus and rabbit, for instance, which are each only $\frac{1}{10}$ mm. (about $\frac{1}{250}$ inch) in diameter, contain comparatively so small an amount of food-yolk as not to interfere materially with the process of segmentation: such ova are called *microlecithal*. When the quantity of food-yolk is relatively greater, the eggs may be described as *megalecithal*: in these the yolk may become

accumulated towards the centre of the egg, eventually leaving a layer of protoplasm comparatively free from yolk round the periphery (*centrolecithal* ova, *e.g.* arthropods); or, as in the case of *telolecithal ova* (Figs. 69, and 181), the yolk-granules may become aggregated more at the lower than at the upper pole (frog), until in the most extreme cases there is only a layer of yolkless protoplasm—the *germinal disc* (dogfish, bird)—lying at the upper pole of the egg.

As yolk is an inert substance, the more of it an egg contains in proportion to the amount of protoplasm, the less actively can the latter divide, and the quantity may be relatively so great in some parts as to prevent segmentation in these parts altogether. We can therefore distinguish between *holoblastic* oosperms, which undergo entire segmentation (*e.g.*, hydra, earthworm, Amphioxus, frog, rabbit), and *meroblastic* oosperms, in which segmentation is limited to that part of the egg in which the protoplasm is comparatively free from yolk (*e.g.*, arthropods, dogfish, bird), this portion, after segmentation, being known as the *blastoderm*. In the centrolecithal ovum it is evident that the segmentation must be *superficial* or *peripheral*, and in the meroblastic telolecithal ovum *discoid*, or restricted to the small *germinal disc* at its upper pole (Figs. 69 and 181). In the case of holoblastic ova the segmenting cells or *blastomeres* may be equal, or nearly equal, in size (*e.g.* Amphioxus, rabbit); or if the yolk is present in greater quantities towards the lower pole, unequal (*e.g.* earthworm, frog).

The influence of the food-yolk in modifying the early process of development is thus evidently very great, and in order to understand these processes in their simplest form it is necessary to select for our study a microlecithal holoblastic egg, such as that of the Amphioxus.

Before reading the next chapter, however, you should once more glance at the account of the development of the tadpole given on pp 210–222, in order to refresh your memory of some of the more important facts and of the terms used.

PRACTICAL DIRECTIONS

A. Special methods are required to follow out the details of the **structure and division of nuclei,** but if you have not the opportunity of examining preparations illustrating this, a good deal may be made out as regards the chromatin and the changes which the chromosomes pass through in the process of mitosis by the following simple method.

Obtain a young gilled-larva or tadpole of the frog (p. 10) and place it in corrosive sublimate for about half an hour, wash thoroughly in water and transfer first into weak and then into strong alcohol (p. 144). Stain entire, either with a solution of *hæmatoxylin* or of *alum-carmine* (p 145).

Strip off small pieces of the skin of the stained preparation, and after putting them through weak and strong alcohol, transfer to absolute alcohol, then to turpentine, xylol, or oil of cloves, and mount in Canada balsam (p. 144). Examine, comparing Fig. 149 and pp 544–549, and sketch as many different stages as possible

B For the **structure of ova,** examine again your sections of the frog's and rabbit's ovary (see pp 208 and 507). Also obtain an unincubated fowl's egg, place it in a small dish about 2½ inches deep: mix some plaster of Paris in water and pour it round the egg (first greasing the latter to prevent it adhering to the plaster) so as to cover the lower half, and then let it set. Fill the dish with normal salt-solution, and with the forceps tap the portion of the shell lying uppermost so as to fracture it, when it can be removed bit by bit. Note: *a*, the accessory parts of the egg developed from the oviduct, viz., the porous *shell*, the double *shell-membrane*—the layers of which are closely applied together except at the thicker end of the egg (see Fig 181), and the *white* or *albumen*, with the twisted *chalazæ* at either end ; and, *b*, the essential part (the *yolk*) with its *vitelline membrane* and circular *blastoderm*, which always floats uppermost.

Living **sperms** have already been examined (see *e.g* pp. 206 and 554, and compare Fig. 180) ; the *head*, *middle piece*, and *tail* should be noted.

C. Observation of the details concerned in the process of **maturation and fertilisation of the ovum** is too difficult for the beginner, but *polar bodies* may be seen in the living, freshly-laid eggs of one of the common pond-snails (*e.g.*, *Limnæa stagnalis*), in which also some of the stages of segmentation can easily be observed. Keep some of these snails in a glass vessel with water-weeds, and notice that the eggs, when laid, are enclosed, a number together, in a common gelatinous envelope. Separate the eggs from one another with needles, and examine in water under the microscope. Note that the small egg is surrounded by fluid enclosed in a relatively large egg-case, and observe the minute polar bodies at the periphery of the ovum

CHAPTER XI

DEVELOPMENT OF AMPHIOXUS: EARLY DEVELOPMENT OF OTHER TYPES, INCLUDING THE CHICK AND RABBIT· FORMATION OF THE CHIEF ORGANS OF VERTEBRATES, AND OF THE AMNION, ALLANTOIS, AND PLACENTA.

THE oosperm of Amphioxus (Fig. 184, A) undergoes binary fission (B), each of the two resulting cells dividing again into two (C). This process is continued until a globular mass of cells or *blastomeres* is produced by the repeated division of the one cell which forms the starting point of the series. Owing to there being rather more yolk at the lower than at the upper pole, the lower cells are slightly larger than the upper, so that the segmentation is not quite equal (D, E) The embryo has now arrived at the *polyplast* or *morula* stage, and sections show that it is hollow, the blastomeres being arranged in a single layer around a central *segmentation-cavity* or *blastocœle* (compare p. 212): such a hollow morula is known as a *blastula* (F, G). The lower side of the blastula then becomes tucked in, or *invaginated,* the result being that the single-layered sphere is converted into a double-layered cup (H, I). This process can be sufficiently well imitated by pushing in one pole of a hollow india-rubber ball with the finger. The resulting embryonic stage is known as the *gastrula*:

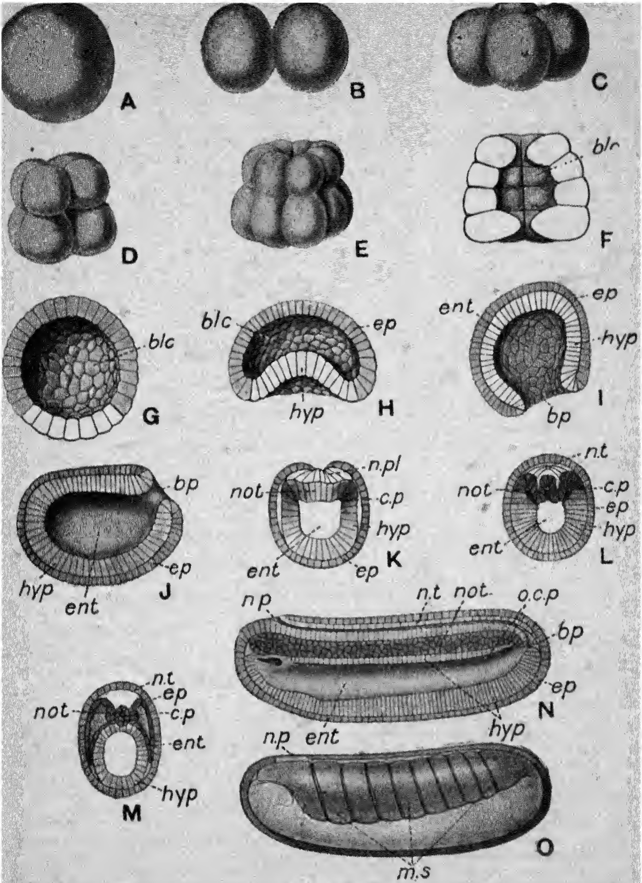


FIG. 184.—Early development of Amphioxus

A, the oosperm, *B*, stage with two blastomeres, *C*, stage with four blastomeres, *D*, stage with eight blastomeres; *E*, stage with sixteen blastomeres; *F*, stage with thirty-two blastomeres cut in half vertically; *G*, blastula stage, cut in half; *H*, early stage of gastrulation, cut in half; *I*, young gastrula in longitudinal section; *J*, older gastrula in longitudinal section, *K*, *L*, *M*, transverse sections of older embryos, showing the formation of the cœlomic pouches or enterocœles, notochord, and medullary tube, *N*, longitudinal section of embryo of about the same age as *L*; *O*, side view of embryo of same age as *N*, with the ectoderm stripped off from one side to show the mesodermic segments formed from the cœlomic pouches

bp. blastopore ; *blc.* segmentation-cavity ; *cp.* cœlomic pouch (enterocœle), *ent.* enteron, *ep* ectoderm, *hyp* endoderm ; *m s* mesodermic segments, *not* notochord, *n p* neuropore, or anterior opening of medullary tube, *n.pl* medullary plate ; *n t* medullary tube ; *o c p* openings of cœlomic pouches into enteron (From Dendy, adapted from Ziegler's models, after Hatschek)

its cavity is the primitive enteron or *archenteron* (*ent*), and is bounded by the invaginated cells which now constitute the *endoderm* (*hyp*), the remaining cells forming the outer wall of the gastrula being the *ectoderm* (*ep*) (compare pp. 212 and 213). The two layers are continuous at the aperture of the cup, the *gastrula-mouth* or *blastopore* (*bp*). Between the ectoderm and endoderm is at first a space, the greatly diminished segmentation-cavity, which soon becomes entirely obliterated, so that the ectoderm and endoderm are in contact. The general resemblance of the gastrula to a simplified Hydra,[1] devoid of tentacles, will be at once apparent, and the stage in the development of the frog's egg represented in Fig. 69, I, though much modified by the quantity of food-yolk (compare p. 212), will be seen to correspond to the gastrula-stage. As in the frog, the blastopore soon closes over, the mouth and anus being subsequently formed from the stomodæum and the proctodæum respectively (p. 215).

The gastrula becomes elongated, flattened on one side and convex on the other (J). The flattened side corresponds to the dorsal surface of the adult, and the blastopore now comes to be situated, as in the frog-embryo (Fig. 69, H, K), at the posterior end of the dorsal surface. A *medullary* or *neural plate* and *groove* (K, *n.pl*) are then formed, the central nervous system being developed in a manner essentially similar to that already described in the case of the tadpole (p. 214), except that

[1] It must, however, be remembered (pp. 306 and 318) that the ectoderm and endoderm of Hydroids are differentiated before the mouth is formed, so that the mouth does not correspond to the blastopore of the gastrula.

the central canal of the medullary or neural cord (L, *n.t*) is formed after the plate is separated from the outer ectoderm. In the mid-dorsal line a thickening of the endoderm (K–N, *not*) soon becomes constricted off to form the *notochord* (pp. 214, 411, and 422), and on either side of this a series of hollow endodermic pouches arise from the archenteron, arranged metamerically (K–O, *c.p*, *o.c.p*, *m.s*). The cavities of these, which subsequently give rise to the body-cavity, are thus at first in free communication with the definitive enteron and are known as *enterocœles;* from their walls the *mesoderm*[1] is derived. Subsequently the communications between the enteric and enterocœlic cavities become closed, and the paired pouches gradually extend between the ectoderm and endoderm, so as eventually to meet one another both dorsally and ventrally (M), their outer walls (parietal or somatic layer of the mesoderm) being in contact with the ectoderm and forming with it the *somatopleure* or body-wall, and their inner walls (visceral or splanchnic layer of the mesoderm) in contact, below the notochord, with the endoderm and with it forming the *splanchnopleure* or wall of the enteric canal (compare p. 214). Thus the body-wall and the enteric canal are separated by a cavity, the *cœlome*, which, much as in the adult earthworm, is divided into a series of metamerically arranged portions: later on, however, the adjacent walls of these cœlomic sacs disappear, and the cœlome becomes a continuous cavity.

The embryo Amphioxus is hatched soon after reaching the gastrula-stage, when it moves about by means of cilia developed on the ectoderm cells, and has to get its own living, having by this time used up its small

[1] The terms *epiblast, hypoblast,* and *mesoblast* are often used to designate the embryonic ectoderm, endoderm, and mesoderm respectively.

reserve of yolk. It then passes through a complicated series of larval stages, gradually leading up to the adult form.

Early Development of other Types.—The presence of a greater amount of food-material in the egg renders it possible for the embryo to go on developing further than the gastrula-stage before being hatched, and, as a general rule, the greater the relative quantity of yolk present in the ovum of an animal, the less clearly can a gastrula-stage be recognised.

In the **earthworm** the segmentation is entire, but unequal, and the larger lower cells become invaginated to form the endoderm and enteron while the smaller upper cells give rise to the ectoderm. In the earthworm the blastopore does not become closed, but gives rise to the mouth.

In the **frog** (p. 212) the enteron arises by a split appearing amongst the yolk-cells, beginning at the edge of the blastopore and gradually extending inwards: the process is supplemented by an invagination of the ectoderm. The enteron is at first a very narrow cleft, but soon widens considerably (Fig. 69, I, *ent*): for some time it does not actually communicate with the exterior, the blastopore (*blp*) being filled up by a yolk-plug (*yk. pl*). As the enteron extends forwards, and the relatively small segmentation-cavity (*bl. cœl*) gradually disappears, the edges of the lower margin of the blastopore approach one another and, uniting in the median plane, give rise to a vertical band at the hinder end of the embryo, in which the three germinal layers are fused together. This band is spoken of as the *primitive streak*, and the faint median groove which runs along it and marks the line of union of the right and left lips of the blastopore is called the *primitive groove*. There is no stage in the frog which exactly corresponds with the

gastrula-stage in Amphioxus, but the stage represented in Fig. 69, I, most nearly approaches to it.

In the centrolecithal egg of the **arthropods** a gastrula-stage is formed by invagination, but as the centre of the oosperm is filled with solid yolk in the place of a segmentation-cavity containing fluid, the invagination only extends a short distance inwards, the enteron being relatively very small and the ectoderm separated from the endoderm by the yolk

The gastrula-stage is much less clearly distinguishable in the segmenting telolecithal eggs of the **dogfish** and **bird** (p. 560), in which the relatively enormous mass of unsegmented yolk is, as in the arthropods, sufficient to nourish the embryo until it has reached a stage closely resembling the adult in almost every essential respect except size. A blastopore can sometimes be recognised in such cases, but in the embryo of the common fowl it is to some extent represented by a *primitive streak* and *groove* (see p. 570 and Fig. 185, E, *pr. st*). The blastoderm becomes differentiated into an outer ectoderm and an inner, lower layer of cells (compare Fig. 185, F), between which and the yolk the enteric cavity is formed: a segmentation-cavity is recognisable in early stages. As the embryo develops, it becomes folded off from the yolk, which is gradually reduced in amount and in later stages is contained in an extra-embryonic part of the embryo—the *yolk-sac* (Fig. 185).

A more detailed account of the early stages of the chick is given below, as the fowl's egg is an easily procurable type for the practical study of development.

The fowl's egg has already been described in detail (p. 551, Fig. 181). Its essential part, the yolk, corresponds, as we have seen, to a single cell enormously enlarged by the mass of yolk-granules it contains, the only part in which they are

absent being a small area which, owing to its lesser specific gravity, is always found at the upper pole; this area, in which the nucleus lies, is known as the *germinal disc*. Fertilisation takes place in the anterior end of the oviduct, and then the nucleus divides and initiates the process of segmentation which is completed by the time the egg is laid, when the germinal disc has thus become converted into a multicellular *blastoderm* (p. 552).

The first stage of segmentation is indicated by the formation of a vertical furrow across the centre of the germinal disc (Fig 185, A), and this is followed by another furrow at right angles to it (B). Further radial and concentric furrows then arise (C) until the blastoderm is seen to consist of a number of irregular cells (D). Horizontal furrows are in the meantime formed, so that the originally single layered blastoderm, beneath which a narrow space representing the *segmentation-cavity* can be recognised, comes to consist of several layers of cells the outer of which corresponds to the *ectoderm*; the inner, or lower layer cells, extend rapidly through the segmentation-cavity between the ectoderm and the yolk and give rise to the *endoderm*, the space remaining beneath this layer and the yolk forming the rudiment of the *enteron* (F). New cells are gradually formed round the edge of the blastoderm, which, when the egg is laid, forms a circular patch, about 3 5 mm in diameter, on the surface of the yolk (Fig. 185): its central part, or *area pellucida*, owing to the presence of fluid in the underlying space, is more transparent than the rim, or *area opaca*.

When the egg is incubated, the blastoderm grows rapidly at its periphery (area opaca), and eventually, as we shall see, encloses the whole yolk. The area pellucida extends less rapidly and becomes pear-shaped in outline (Fig. 185, E), its broader end corresponding to what will become the anterior end of the embryo: in this region most of the lower layer cells are arranged so as to form a definite layer of endoderm, which can be recognised somewhat later in the area opaca also. The ectoderm and lower layer cells are at first continuous round the edge of the blastoderm, but later on this is only the case at the posterior border (F), and results in the appearance of a narrow band, the *primitive streak* (E, *pr. st*), along which a median *primitive groove* is formed. This, as already mentioned, represents the fused lips of the blastopore of the frog and other forms; it extends from the centre to the posterior border of the area pellucida, and rapidly grows backwards. The primitive streak is due to the multiplication of ectoderm cells, which grow inwards

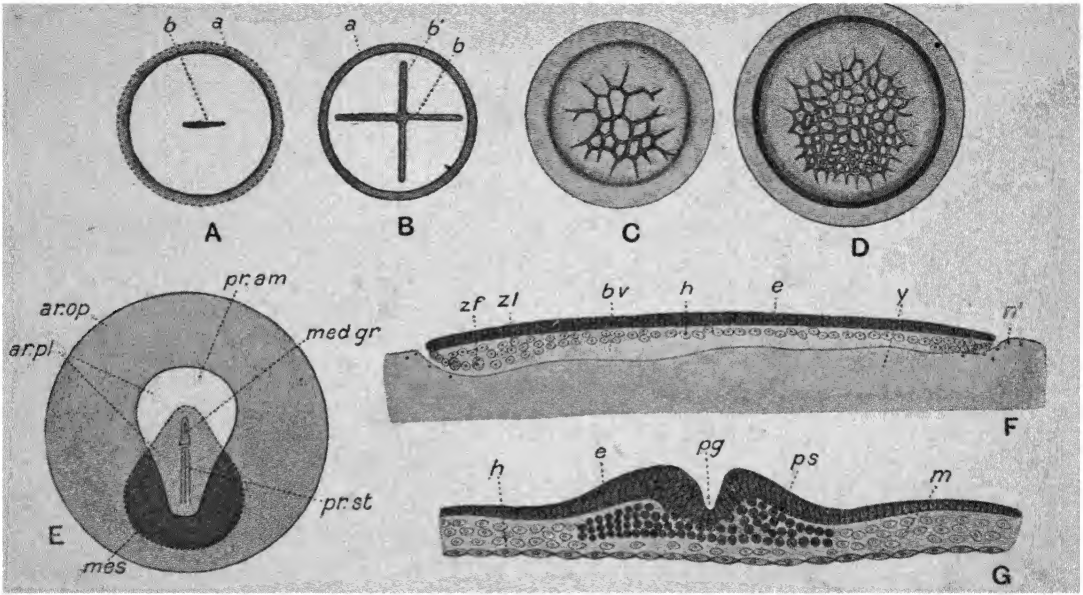


FIG 185 —Early stages in the development of the blastoderm in a Fowl's egg
A, germinal disc, showing first segmentation furrow, *B*, second furrow, *C*, later stage with numerous blastomeres; *D*, stage towards completion of segmentation (*A*—*D* × 7½); *E*, Diagram of blastoderm at about the twentieth hour of incubation (× 6);

F, vertical section of blastoderm and adjacent part of the egg at the time of laying, before incubation the anterior edge of the blastoderm is to the right, the posterior edge to the left of the figure (× 25); *G*, transverse section of blastoderm at about the twentieth hour of incubation, the section passing through the primitive streak and groove at about the middle of its length (× 200)
a. periphery of germinal disc; *ar op* area opaca; *ar pl* area pellucida, *b* first, and *b′* second furrow, *bv* rudiment of enteron, *e* ectoderm, *h* endoderm; *n′*. nucleus in yolk around which a cell will be formed later, *m mes* mesoderm, *med gr* medullary groove, *pg* primitive groove; *pr am* pro-amnion, *pr st* primitive streak, *y* yolk, *zf* formative cell, *sl*. lower layer cells (*A* and *B*, from Foster and Balfour, *C*—*G*, from Marshall, after Duval and Coste)

and spread out right and left under the covering ectoderm, between it and the endoderm, so as to form a horizontal wing of cells on either side (G) The *mesoderm* is formed from these wing-like ectodermic sheets, with which the endoderm becomes united, so that the three layers are for a time indistinguishable in this region The mesoderm eventually forms a sheet of loosely arranged cells which spreads rapidly in all directions except anteriorly (E), in which region, known as the *pro-amnion*, the blastoderm consists of ectoderm and endoderm only until the end of the second day of incubation, and by the third day the three germinal layers have become established in the whole of the blastoderm

Before tracing the development of the various organs derived from the three germinal layers respectively, it must be remembered that the actual chick embryo is formed from the area pellucida, and gradually becomes folded off from the yolk, while the area opaca extends over the yolk until the latter is entirely covered by it (17th day of incubation): thus we can distinguish between an *embryonic* and an *extra-embryonic* portion of the blastoderm. In the mesoderm of the latter portion blood-vessels are formed, so that it is then known as the *area vasculosa* (see Fig. 185 E).

The minute egg of the **rabbit** (compare p. 509) and of most other mammals, although microlecithal and undergoing a holoblastic segmentation, has presumably been derived from a meroblastic type with abundant yolk, like that of the bird, and some lower mammals (*Ornithorhynchus* and *Echidna*) living in Australia at the present day still possess eggs of this type. In the higher Mammalia the yolk has disappeared, as it is no longer needed, the embryo, as we have seen (p. 509), being nourished by means of a *placenta*, which will be described

presently. The early processes of development are therefore somewhat peculiar, and though the segmentation is holoblastic, the subsequent development is for some time essentially similar to that of the bird: it is not until later stages that the more special characteristics of the mammal on the one hand and the bird on the other become apparent.

Fertilisation and segmentation take place in the uterine tubes (p 508), and each oosperm is surrounded by a membrane, the *zona radiata*, apparently formed from the follicle cells, and a layer of albumen secreted from the oviduct. The oosperm divides into two blastomeres (Fig 186, A), and then further divisions follow and result in the formation of a mulberry-like mass (B), which, however, is not hollow, as in Amphioxus (Fig 184), but consists of an outer layer enclosing a solid mass of larger and more granular cells (C), and at this stage it passes into the uterus The outer layer of cells then grows rapidly, so that a space appears and gradually increases in size, between it and the inner mass except at one point where the latter is attached to the former (D, E). This hollow ball is known as the *blastocyst* or *blastodermic vesicle*, and may be compared to the embryo and yolk-sac of a bird, except that the latter contains a fluid instead of yolk. The outer layer is called the *trophoblastic ectoderm* or *trophoblast*, it probably corresponds to the extra-embryonic ectoderm of the chick (p 572) and takes no direct part in the formation of the embryo, which arises from the inner mass (*embryonic area*), in much the same way as the chick is formed from the blastoderm in the case of the fowl's egg. Thus later on an embryonic portion with a primitive streak, and an extra-embryonic portion gradually growing round beneath the trophoblast, can be recognised in the embryonic area, the body of the embryo being gradually folded off from the blastocyst, which is then often known as the *umbilical vesicle* and has similar relations to the embryo as the yolk-sac has to the body of the chick, to which it corresponds (see p. 569 and Figs. 185 and 191).

In Amphioxus alone amongst the triploblastic animals described in this book does the mesoderm arise as a series of enterocœlic pouches: as we have seen, it is usually at first solid, and may be budded off from the

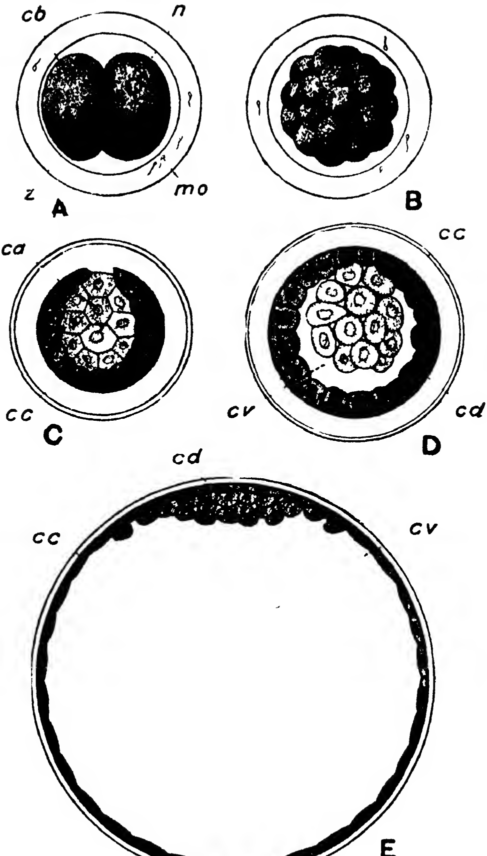


FIG. 186 —Early stages in the development of the oosperm of the Rabbit.
A, two-celled stage, from middle part of the uterine tube, about twenty-two hours after copulation ; *B*, polyplast or morula stage, from lower end of uterine tube, about the middle of the third day ; *C*, close of segmentation, from lower end of uterine tube just before entering uterus, seventy hours after copulation ; *D*, first stage in formation of blastocyst, from uterus, seventy-five hours after copulation ; *E*, section of blastocyst at the end of fourth day. (× about 160)
cb, blastomere ; *cc*, trophoblastic ectoderm ; *cd*, inner mass of cells (embryonic area) ; *cv*, cavity of blastocyst , *mo*, sperms imbedded in the zona radiata (*z*) ; *n*, nucleus. (From Marshall , *A*, *B*, after Bischoff ; *C—E* after Van Beneden.)

ectoderm and endoderm, or from the ectoderm only, at the margin of the blastopore or primitive groove (chick, p. 607); or both endoderm and mesoderm may be differentiated at the same time from the lower-layer cells or yolk-cells (frog, p. 213); or finally, it may arise in all these ways. The cœlome is formed secondarily by a split taking place in the mesoderm on either side (Figs. 197 and 199), the split gradually extending with the extension of the mesoderm between the ectoderm and endoderm. Thus the cœlome is formed, not as an enterocœle, but as a *schizocœle.*

In Vertebrates each mesoderm-band becomes differentiated into a dorsal portion abutting against the medullary cord and notochord known as the *vertebral plate*—which soon loses its cœlomic space, and a ventral portion, the *lateral plate*, which is divided into parietal and visceral layers by the cœlome (Figs. 70 and 199 B, C). The vertebral plate undergoes metameric segmentation, becoming divided into a row of squarish masses, the *mesodermal segments* or "*protovertebræ*" (*pr. v, ms. s*), from the outer parts of which (*muscle-plates*, the muscular segments or myomeres are formed (p. 410), and from the inner parts the vertebral column, the segmentation of which alternates with that of the myomeres.

Outline of the Development of the Chief Organs in the Vertebrata (compare pp. 212–222).—The **nervous system** as well as the essential parts of the **sensory organs,** are, as we have seen, in all cases formed from the ectoderm. The development of the central nervous system takes place in essentially the same manner as in Amphioxus (p. 566) and frog (p. 214).

In the chick the ectoderm in front of the primitive streak early becomes thickened along the median line to form the *medullary plate* (Fig. 185, E); this gradually increases in

length at the expense of the primitive streak, from the cells of which the greater part of the embryo is eventually developed. A *medullary groove*, bounded by *medullary folds* (Fig. 187, A and B), is formed along the median line of the medullary plate and passes into the primitive groove posteriorly; while near their anterior ends the folds meet and unite, so as to constrict off a *medullary tube* from the

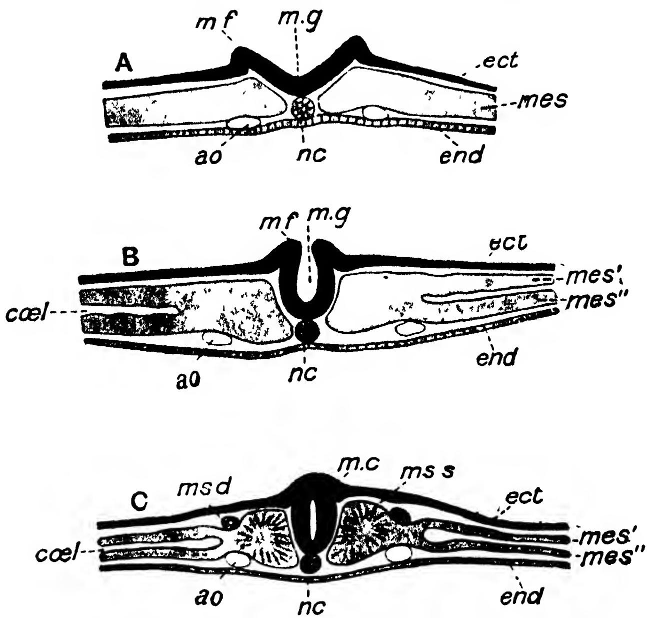


FIG 187.—Transverse sections across the body of a chick embryo at the twenty-fourth to thirtieth hour of incubation, to show stages in the formation of the medullary cord and cœlome (× 100)
ao aorta, *mes* mesoderm, *mes'* parietal, and *mes"* visceral layer of mesoderm, *m f* medullary fold, *m g* medullary groove, *ms d* mesonephric duct, *ms s.* mesodermal segment, *nc* notochord

outer ectoderm (Figs 185, E and 187, A). This closure of the tube then gradually extends both forwards and backwards, the groove remaining open longest at its posterior end. In the region of the pro-amnion (p 572, Figs. 185, E, and 187, A) a transverse crescentric fold of both ectoderm and endoderm, extending across the pellucida a short distance

in front of the anterior end of the embryo (*head-process*), is formed as the *head-fold* and marks off the anterior end of the embryo from the rest of the blastoderm.

In Vertebrates the anterior end of the hollow medullary tube becomes dilated, forming three bulb-like swellings—the fore-brain (Fig. 188, A, *f. b*), mid-brain (*m. b*), and hind-brain (*h. b*). Soon another hollow swelling grows forwards from the first vesicle (B, *prs. en*), and the third gives off a similar hollow outgrowth (*cblm*) from its dorsal surface. The brain now consists of five divisions: the *prosencephalon* (*prs. en*) and *diencephalon* (*dien*) derived from the fore-brain, with the pineal structures (*pn. b, pn. e*) and the infundibulum, to which the pituitary body becomes attached (*inf, pty*); the *mid-brain* or *mesencephalon* (*m. b*), which gives rise to the *optic lobes* and *crura cerebri*; and the *epencephalon* or *cerebellum* (*cblm*) and *metencephalon* or *medulla oblongata* (*med. obl*) derived from the hind-brain. The original cavity of the brain becomes correspondingly divided into a series of chambers or *ventricles* (compare Figs. 55 and 188), all communicating with one another, and called respectively the *fore-ventricle* or *prosocœle, third ventricle* or *diacœle, mid-ventricle* or *mesocœle* (*iter*, and *optic ventricles* or *optocœles*), *cerebellar ventricle* or *epicœle*, and *fourth ventricle* or *metacœle*.

In some fishes (*e.g.* dogfish) the brain consists throughout life of these five divisions, but in most cases (Figs. 54 and 158) the prosencephalon grows out into paired lobes, the right and left *cerebral hemispheres* or *parencephala* (Figs. 188, I–L, *c. h*), each containing a cavity, the *lateral ventricle* or *paracœle* (*pa. cœ*) which communicates with the diacœle (*di. cœ*) by a narrow passage, the *foramen of Monro* (*f. m*). From the prosencephalon or the hemispheres are given off a pair of anterior prolongations, the *olfactory lobes* or *rhinencephala*

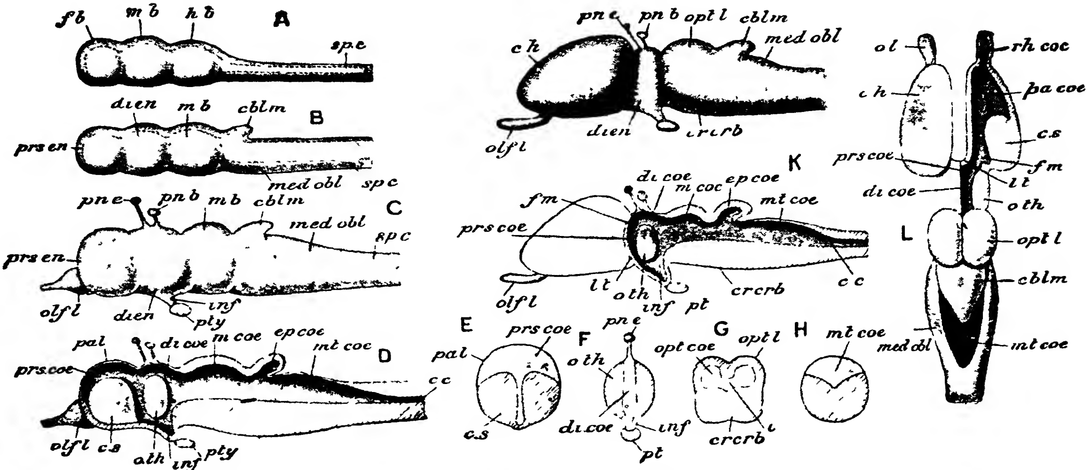


FIG. 188.—Diagrams of the Craniate Brain

A, First stage, side view the cavity indicated by a dotted line, *B*, second stage, *C*, side view of fully-formed brain with undivided prosencephalon, *D*, the same in sagittal section, *E*, transverse section of prosencephalon, *F*, of diencephalon, *G*, of mesencephalon; *H*, of metencephalon, *I*, side view of brain with cerebral hemispheres, *K*, sagittal section of the same, *L*, dorsal view, the cavities exposed on the right side

cblm cerebellum, *c c* central canal; ***cr crb*** crura cerebri, *c h* cerebral hemispheres, *c. s* corpora striata; ***di coe*** diacœle or third ventricle, ***dien*** diencephalon, ***ep coe*** epicœle; *f b* fore-brain, *f m* foramen of Monro, *h b* hind-brain, ***inf*** infundibulum; *i* iter; *l t.* lamina terminalis, *m b* mid-brain, ***m coe*** mesocœle, ***med obl*** medulla oblongata; ***mt coe*** metacœle or fourth ventricle; ***olf l*** olfactory lobes, ***opt cœ*** optocœles, ***opt l*** optic lobes, *o th* optic thalami, ***pa cœ*** paracœles or lateral ventricles, ***pal*** pallium, or roof of prosencephalon, ***pn. b*** pineal body, ***pn e*** pineal or parietal eye (compare p 167), ***prs coe*** prosocœle, ***prs en*** prosencephalon; ***pt pty.*** pituitary body; ***rh.cœ*** rhinocœles or olfactory ventricles, ***sp c*** spinal cord. (From Parker and Haswell's *Zoology*)

(*olf. l*), each containing an *olfactory ventricle* or *rhinocœle* (*rh. cœ*).

In the preceding description the brain has been described as if its parts were in one horizontal plane; but, as a matter of fact, at a very early period of development the anterior part becomes bent down over the end of the notochord so that the whole organ assumes a retort-shape, the axis of the fore-brain being strongly inclined to that of the hind-brain. The bend is known as the *cerebral flexure* (Fig. 190, B): it is really permanent, but as the hemispheres grow forwards parallel to the hind-brain, and the floor of the mid-brain and hind-brain thickens, it becomes obscure and is not noticeable in the adult

The central cavity of the embryonic spinal cord has at first the form of a narrow vertical slit (Fig. 187, *c*), the walls of which eventually fuse dorsally, while ventrally part of the slit forms the central canal of the adult spinal cord. The lateral walls continue to thicken and finally the cord becomes approximately circular in section and the dorsal and ventral fissures are developed.

The ganglia of the dorsal roots of the *spinal nerves* are developed from a paired *neural crest* (Fig. 196, *n. cr*) arising close to the junction of the medullary plate and outer ectoderm: this becomes segmented to form the ganglia, from the cells of which the sensory fibres arise and extend into the spinal cord. The ventral roots arise as direct outgrowths from cells in the ventral region of the medullary cord. Certain of the *cerebral nerves* are developed in an essentially similar manner to the dorsal roots of the spinal nerves, while others arise as direct ventral outgrowths from the brain, like the ventral roots. The fibres of all the typical nerves grow peripherally until they reach the parts which they ultimately supply.

The *olfactory organs* arise as sac-like invaginations of the ectoderm, one on either side of the snout (Fig. 188), and become enclosed by the cartilaginous

olfactory capsules, developed, with the rest of the skeleton, from the mesoderm. The aperture of invagination gives rise to the external nostril, the internal nostrils (in air-breathing forms) being developed subsequently.

The mode of development of the paired *eye* of vertebrates is peculiar and characteristic.

At an early stage of development a hollow outgrowth —the *optic vesicle* (Fig. 189, A, *op. v*)—is given off from either side of the fore-brain and extends towards the side of the head, where it meets with an in-pushing of the ectoderm (*l*), which becomes thickened, and finally, separating from the ectoderm, forms a closed, spherical sac (B, *l*) with a very small cavity and thick walls (compare Figs. 69, L, *e*, and 189). This body is the rudiment of the lens: as it enlarges it pushes against the optic vesicle, which becomes invaginated, the single-layered optic vesicle, thus being converted into a two-layered *optic cup* (Fig. 189, B, *oc'*, *oc"*), its cavity, originally continuous with the diacœle, becoming obliterated. Between the edge of the cup and the lens, on the ventral side, is a small space which gradually extends towards the stalk of the cup, and thus gives rise to a slit in the wall of the latter: this *choroid fissure* C, *aus*), as it is called, soon becomes closed by the union of its edges. The outer layer of the optic cup gives rise to the pigment-layer of the retina (p. 197): from its inner layer the rest of the retina—including the rods and cones—is formed. The stalk of the optic cup occupies, in the embryonic eye, the place of the optic nerve, but the actual fibres of the nerve are formed from the nerve-cells of the retina and grow inwards to the brain.

During the formation of the lens, mesoderm extends in between the ingrowth from which it arises and the

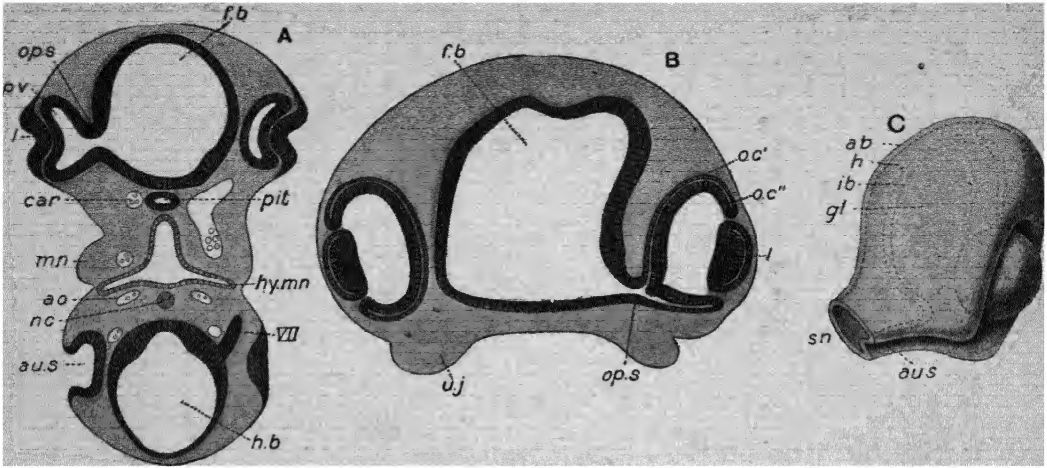


FIG 189—*A*, Transverse section across the head of a Chick embryo at the forty-eighth hour of incubation, the section is taken along a line corresponding to one joining the reference letters *au s* and *l* in the three-day embryo shown in Fig 202, *B*, owing to the cerebral flexure, both fore-brain and hind-brain are cut by the section, the right side of the section is slightly anterior in position to the left side (× 45), *B*, transverse section across the fore-brain and eye of a chick embryo at the sixtieth hour of incubation, on the right side the section passes through the optic stalk, and on the left side just behind the stalk (× 35), *C*, plastic representation of the optic cup and lens (*A* and *B*, after Marshall, *C*, after Hertwig)

A and ***B***—***ao*** aorta, ***au s*** auditory pit, ***car*** carotid artery, ***f b*** fore-brain, ***h b*** hind-brain, ***hy mn*** hyomandibular cleft, ***l*** lens, ***mn*** mandibular arch, ***nc*** notochord, ***o c'***. outer, and ***o c"***. inner wall of optic cup, ***op v*** optic vesicle, ***op s*** optic stalk, ***pit*** pituitary body, ***u j*** upper jaw, ***VII*** facial nerve

C—***ab*** outer wall of optic cup, ***aus*** choroid fissure, ***gl*** cavity of optic cup, ***h*** space between the two walls, which afterwards disappears, ***ib*** inner wall of optic cup, ***l*** lens, ***sn*** stalk of optic cup (rudiment of optic nerve)

external ectoderm ; from this the main substance of the cornea and its inner or posterior epithelium are formed, the adjacent ectoderm becoming the external epithelium, *i.e.*, that of the conjunctiva (p. 194). Mesoderm also makes its way into the optic cup through the choroid fissure, and gives rise to the vitreous humour. Lastly, the mesoderm immediately surrounding the optic cup is differentiated to form the choroid, the iris, and the sclerotic.

Thus the eye of Vertebrates has a threefold origin : the sclerotic, choroid, iris, vitreous humour, and the greater part of the cornea are mesodermal ; the lens and external epithelium of the cornea are derived from the ectoderm of the head : the retina and optic nerve are developed from a hollow pouch of the brain, and are therefore in their ultimate origin ectodermal. The sensory cells of the retina—the rods and cones—although not directly formed from the external ectoderm, as in Invertebrates, are ultimately traceable into the superficial layer of ectoderm, since they are developed from the inner layer of the optic cup, which is a prolongation of the inner layer of the brain, the latter being continuous, before the closure of the medullary groove, with the ectoderm covering the general surface of the body (compare Figs. 69 and 201).

The *organ of hearing*, like that of smell, arises in the embryo as a paired invagination of the ectoderm in the region of the hind-brain, a shallow depression being formed (Figs. 69, L, 189, A, and 190, *au. s*) which deepens and becomes flask-shaped ; and finally, as a rule, loses its connection with the external ectoderm, giving rise to a closed sac surrounded by mesoderm in which the cartilaginous auditory capsule is subsequently developed. At first simple, it soon becomes divided by a constriction into dorsal and ventral compartments, from the former of which arise the utriculus and semicircular canals, and from the latter the sacculus and cochlea.

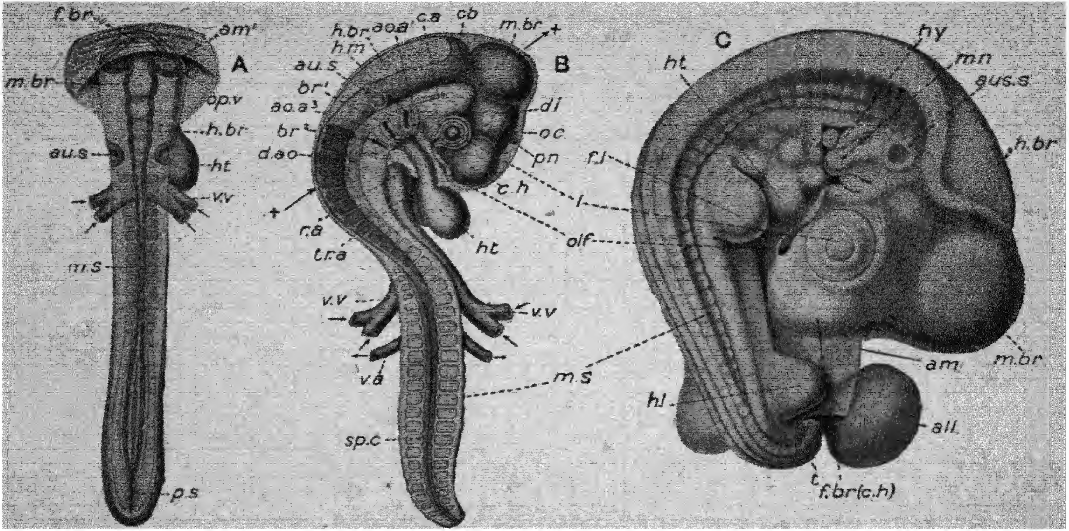


Fig 190—Chick embryos at, *A*, the thirty-sixth hour of incubation, *B*, the end of the third day, and *C*, the fifth day. (× 15) (Compare Fig 191)

am ¹ head-fold of the amnion · ***all*** allantois, ***a o*** ¹, ***ao*** ³, first and third aortic arches, ***au s***, ***aus s***, auditory sac, ***br*** ¹, ***br*** - first and second branchial clefts, ***am*** cut edge of amnion, ***am*** ¹ pro-amnion, ***c a*** carotid artery, ***cb*** cerebellum, ***c h.*** cerebral hemisphere, ***d ao*** dorsal aorta; ***di*** diencephalon, ***f br*** fore brain, ***f l*** fore-limb, ***h br*** hind-brain, ***h l*** hind-limb, ***h m*** hyomandibular cleft, ***ht*** heart (ventricle), ***hy*** hyoid arch, ***l*** lens of eye, ***m br*** mid-brain, ***mn*** mandibular arch, ***m.s*** mesodermal segments, ***o c.*** optic cup; ***olf*** olfactory pit, ***op v*** optic vesicle, ***pn*** pineal body, ***r a*** right auricle, ***sp c.*** spinal cord, ***t*** tail, ***tr a*** conus arteriosus, ***v.a.*** vitelline artery; ***v.v.*** vitelline vein (*A* and *B*, from Marshall; *C*, from Parker and Haswell after Duval)

The early development of the **enteric canal** has already been dealt with in the case of the frog (pp. 212 and 215), and it will be remembered that the greater part of it (*mesenteron*) is lined by endoderm, its cavity being at first bounded by the yolk below, but gradually becoming closed in by endoderm cells. When a yolk-sac is formed (dogfish, bird, mammal, Figs. 185, 191,) it of course communicates with the mesenteron; but as the embryo is gradually folded off from the yolk-sac, the mesenteron becomes tubular along its whole length, and eventually the stalk of the yolk-sac becomes solid, at hatching (or birth) its point of communication with the body being marked by the *navel* (*umbilicus*). The ectodermic *stomodæum* (p. 215), which gives rise to the mouth-cavity and also to the greater part of the pituitary body, comes to communicate with the mesenteron anteriorly, and the ectodermic *proctodæum* opens into it posteriorly. The muscular and peritoneal layers of the canal are formed, it will be remembered, from the mesoderm.

The first traces of the *liver* (Fig. 69, K) and *pancreas* are seen as simple endodermic offshoots of the mesenteron, which gradually become branched in a complicated manner, the numerous lobules being more or less closely connected together by mesoderm. The *gill-pouches* arise as paired outgrowths of the endoderm lining the pharynx, which come into contact with the ectoderm, the latter becoming perforated to form the external branchial apertures. The bars, with their contained skeletal and vascular structures, which separate the pouches, are called the visceral arches; there are similar skeletal and vascular structures in front of the first and behind the last cleft; so that, in all, five visceral arches are reckoned, with four intervening gill-clefts. Four gill-clefts appear also in the embryo of reptiles, birds, and mammals—

FIG 210—Forty different breeds of Pigeon, all descended from the common Rock Pigeon (*Columba livia*) (see **Fig 138**), illustrating the results of Artificial Selection From Burlend's *First Book of Zoology*)

become developed from the original one." (Parker and Haswell.)

The effect of natural selection as an evolutionary factor has thus been summarised:

a. Under new conditions harmful characters will be eliminated by selection.

b. Beneficial characters are intensified and modified so as to be even more useful.

The great body of characters neither hurtful nor beneficial will not be modified, but will persist through heredity.

The resultant of all these existing conditions (of environment) is, according to Darwin and his followers, an inevitable natural selection of individuals and of species. Thousands must die where one or ten may live to maturity (*i.e.* to the time of producing young). Which ten of the thousand shall live depends on the slight but sufficient advantage possessed by ten individuals in the complex struggle for existence due the fortuitous possession of fortunate congen differences (variations). The nine hundred and with unfortunate congenital variations are extir in the struggle and with them the opportunit perpetuation (by transmission to the offsprir particular variations. There are thus left ten their advantageous variations. The off ten, of course, will vary in their turn around the new and already prov parental condition: amongst the tho of the original saved ten the same and food will again work to the killi of nine hundred and ninety, leavin to reproduce. This repeated a

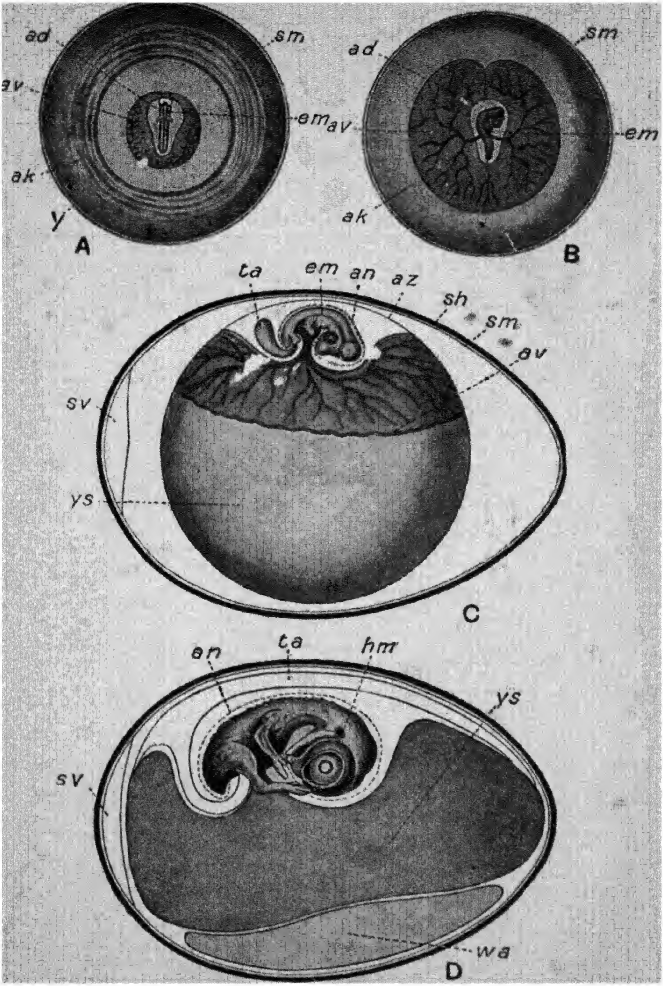


FIG 191.—The yolk of a Hen's egg at, *A*, the thirty-sixth hour from the beginning of incubation, *B*, the third day, *C*, the end of the fifth day, and *D*, the end of the ninth day (about nat size) (Compare Fig. 190.)

ad, area pellucida, ***an*** inner or "true" amnion; ***ak***, area opaca, ***av***, area vasculosa, (in *C* its outer margin), ***az*** outer or "false" amnion (serous membrane); together with the vitelline membrane, ***em*** embryo, ***hm***, hyomandibular cleft; ***sh*** egg-shell; ***sm*** vitelline membrane (in *C*, shell membrane), ***sv*** air-chamber; ***ta*** allantois; ***wa*** white or albumen; ***y y*** yolk-sac (From Marshall)

eventually give rise to the hepatic portal veins. The chief somatopleuric veins in all embryonic Vertebrate are, as in the dogfish, the jugulars and the cardinals (Figs. 204 and 208). In all Vertebrates above the fishes, the cardinals become subsequently more or less entirely replaced functionally by the postcaval: the anterior part of one or both cardinals may, however, persist as the azygos vein or veins (*e.g.* rabbit, p. 489).

Urinogenital Organs.—The *excretory organs*, speaking of Vertebrates as a whole, arise as a series of tubules having the general character of *nephridia* (pp. 154 and 342) situated along the dorsal region of the cœlome, but owing to the fact that they do not all arise at the same time and that their development is modified by neighbouring structures, there is much variation as regards these tubules and their relations. They may in general be classified into three groups, constituting what are known respectively as the *fore-kidney* or *pronephros* (Fig. 194, A, *p. nph*), the *mid-kidney* or *mesonephros* (*ms. nph*), and the *hind-kidney* or *metanephros* (*mt. nph*).

The *pronephros* appears at an early stage of development, and very rarely remains functional throughout life, though in some cases (*e.g.* tadpole) it serves as an excretory organ in the larva: in many cases it is merely represented by vestiges (*e.g.* dogfish, bird, rabbit). The pronephric tubules open at one end into the cœlome by ciliated nephrostomes, and at the other into a longitudinal *pronephric duct* (*sg. d*), which communicates with the cloaca posteriorly. They are generally from two to four in number, are not strictly segmental, and are confined to the anterior end of the cœlome: opposite their nephrostomes a single large glomerulus (see p. 155) is present on either side of the body.

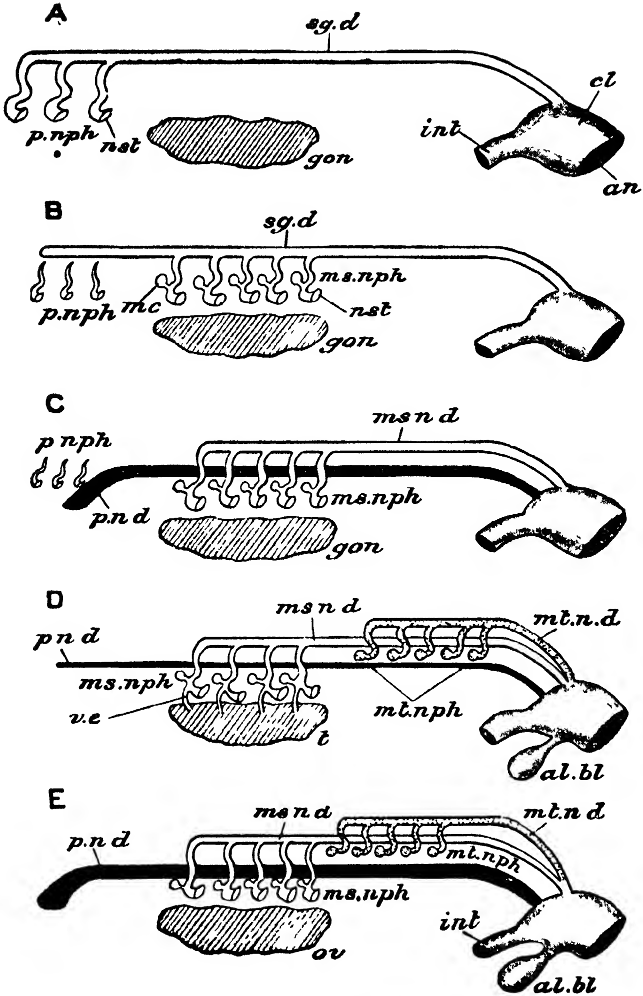


FIG. 194.—Diagrams illustrating the development of the urinogenital organs of Vertebrate.

A, pronephros in functional activity, *B*, atrophy of pronephros, development of mesonephros; *C*, condition in the adult female frog showing differentiation of Wolffian and Müllerian ducts, D, E, condition found in the higher craniate, showing *D*, development of metanephros, male type, *E*, female type

al bl. allantoic bladder, *an.* anus, *cl* cloaca, *gon* gonad, *int* intestine, *mc* Malpighian capsule, *msn d* mesonephric (Wolffian) duct, *ms nph.* mesonephros, *mt n d* metanephric duct, *mt nph* metanephros, *nst* nephrostomes, *ov.* ovary, *p n d.* Mullerian duct, *p nph* pronephros, *sg d* pronephric or segmental duct, *t.* testis, *v e* efferent ducts (From Parker and Haswell's *Zoology*)

The *mesonephros* appears rather later than the pronephros, and extends along the greater part of the cœlome. Its tubules are segmentally arranged, and thus furnish another example of metamerism in the Vertebrate body; each tubule is provided with a separate glomerulus enclosed within a Malpighian capsule (*mc*). The nephrostomes of the mesonephros may lose their connection with the tubules and come to open into certain veins (*e.g.* frog, Fig. 52), or may disappear at a later stage to a greater or less extent (dogfish) or entirely (*e.g.* bird, rabbit): at their other ends the tubules communicate with the pronephric duct, which may now be spoken of as the *mesonephric duct* (Fig. 194, *ms. n. d, ms. t*). In Fishes and Amphibians (Fig. 194, C) the mesonephros remains as the functional kidney throughout life, though the posterior part alone may retain the renal function and develop special ducts (dogfish), thus foreshadowing the metanephros of higher Vertebrates.

The *metanephros* is characteristic of Reptiles, Birds, and Mammals (Fig. 194, D and E). Its tubules arise later than those of the mesonephros and open into a special ureter or *metanephric duct* (*mt. n. d*), which arises as an outgrowth from the posterior end of the mesonephric duct: they resemble the mesonephric tubules except that they possess no nephrostomes and usually show no signs of a metametric arrangement.

In the majority of Vertebrates the *generative organs* take on a close connection with certain of the urinary tubules and their ducts (p. 205), which may thus

undergo a change of function. In the dogfish the pronephric duct early undergoes longitudinal subdivision into two, one of which is retained as a mesonephric duct (now often spoken of as the *Wolffian duct*); while the other (*Müllerian duct*), retaining its connection anteriorly with the cœlome by a persistent pronephric nephrostome, assumes the function of an oviduct in the female, and atrophies in the male, though traces of it may persist in the adult. Owing to the connection which is formed between the testis and certain of the mesonephric tubules by means of efferent ducts, the Wolffian duct may now serve as a urinogenital duct (frog, p. 205); or when an *epididymis* is formed from the mesonephros (Fig. 194, D), and special ureters arise in connection with the functional renal tubules, the Wolffian duct serves as a spermiduct mainly if not entirely (mammal, p. 506).

In most Vertebrates the oviducts arise quite independently of the mesonephric ducts, each being formed as a groove of the cœlomic epithelium which becomes closed in and grows from before backwards to the cloaca, its anterior opening into the cœlome representing a nephrostome of the pronephros.

In the higher Vertebrates, in which the kidney of the adult is a metanephros (p. 590), the only parts of the mesonephros and its duct which persist as more than a vestige are the epididymis and spermiduct of the male.

The *gonads* arise as ridges covered by cœlomic epithelium on the dorsal wall of the body-cavity close to the inner side of the developing kidneys. Their epithelium is known as *germinal epithelium*, and from it either ova or sperms are eventually developed (pp. 206–207, and 507).

The majority of the **muscles** are developed, as we have seen (pp. 215 and 575), from the mesodermal

segments, others arising from the parietal and visceral layers of the mesoderm.

The first part of the **endoskeleton** to be formed is the *notochord* (pp. 215 and 567), developed primarily from the endoderm, but in the chick and rabbit arising from the central part of the mass of cells continued forwards from the front end of the primitive streak where the endoderm and mesoderm are united in a secondary median fusion for some time In the mesoderm surrounding the notochord cartilages appear and give rise to the *vertebræ*, the notochord becoming constricted by the ingrowing cartilage and eventually disappearing more or less completely (p. 422): it at first extends into the head as far as the pituitary body (Fig. 195). The cranial cartilages do not become segmented, but give rise to a pair of horizontal bars, the *parachordals* (*pa. ch*): these are continued forwards, diverging around the pituitary body, as the *trabeculæ cranii* (*tr*). The two parachordals and trabeculæ then unite respectively with one another, and so form a firm floor for the future

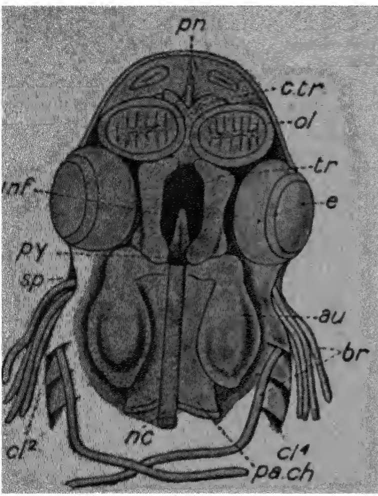


FIG 195.—Dissection of the head of an embryo Dogfish (*Scyllium canicula*) from the dorsal side, to show the developing chondrocranium (dotted) (× 8) *au.* auditory capsule, *br* external gills, *c tr.* cornu of trabecula; *cl*2, *cl*4 gill-clefts, *inf* infundibulum of brain (left *in situ*), *nc.* notochord; *ol.* olfactory sac, *pa ch* parachordal cartilage, *pn* prenasal cartilage, *py.* pituitary body (left *in situ*); *sp.* spiracular cleft, *tr* trabecula. (After W. K Parker)

brain-case: this is gradually developed by the cartilage growing up on either side and eventually meeting to a greater or less extent above the brain: there is never, however, a complete cartilaginous roof to the cranium, parts of which are only membranous and form the fontanelles (pp. 45 and 420). In the meantime the cartilaginous sense-capsules are developed, the olfactory and auditory capsules uniting with the brain-case in front and behind respectively.

The *visceral skeleton* is formed as a series of cartilaginous bars within the visceral arches, the first of which forms the mandibular arch, the second the hyoid, and the others the branchial arches.

The limbs appear as small buds (Fig. 190, C) composed of ectoderm with a core of mesoderm, in which latter their skeleton arises by the formation of cartilage extending inwards to form the arches, and outwards to form the skeleton of the free portions of the limbs.

As we have seen, the endoskeleton may remain practically entirely cartilaginous in the adult (*e.g.* dog-fish), but in higher forms extensive processes of ossification set in, certain bones replacing the cartilage to a greater or less extent, and others being formed in the surrounding connective-tissue (compare p. 45).

Development of the Amnion, Allantois, and Placenta.—We must now consider some important and characteristic structures which are developed in the embryos of Reptiles, Birds, and Mammals, and known as *embryonic membranes*. Taking the chick as a convenient example, these are formed as follows.

The blastoderm, as we have seen (p. 569 and Fig. 191), gradually extends peripherally so as to cover the yolk, and thereby becomes divisible into an *embryonic portion*, from which the embryo is formed, and an *extra-*

embryonic portion, which invests the yolk-sac and takes no direct share in the formation of the embryo. The extension of the ectoderm and endoderm takes place regularly and symmetrically; but the mesoderm, while extending equally in the lateral and posterior regions, grows forwards in the form of paired prolongations which afterwards unite, so that for a time there is an area of the blastoderm in front of the head of the

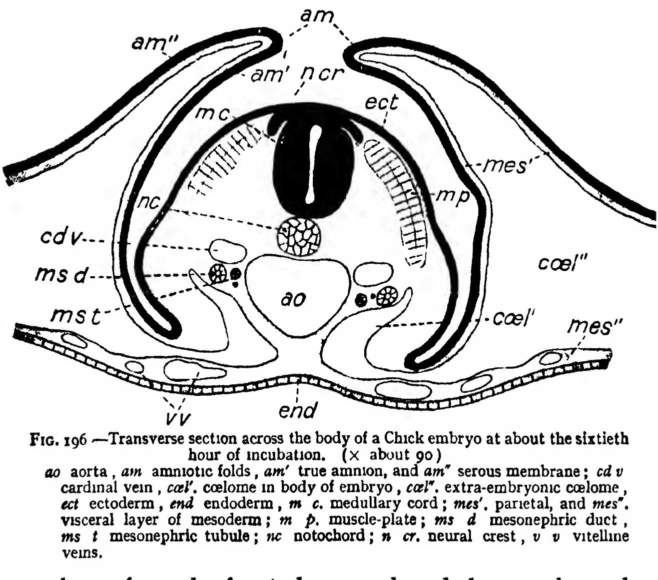


FIG. 196.—Transverse section across the body of a Chick embryo at about the sixtieth hour of incubation. (× about 90.)
ao aorta, *am* amniotic folds, *am'* true amnion, and *am''* serous membrane; *cd v* cardinal vein, *cœl'*. cœlome in body of embryo, *cœl''*. extra-embryonic cœlome, *ect* ectoderm, *end* endoderm, *m c.* medullary cord; *mes'*. parietal, and *mes''*. visceral layer of mesoderm; *m p.* muscle-plate; *ms d* mesonephric duct, *ms t* mesonephric tubule; *nc* notochord; *n cr.* neural crest, *v v* vitelline veins.

embryo formed of ectoderm and endoderm only and called the *pro-amnion* (p. 572 and Fig. 187, E, *pr. am*).

Before the embryo has begun to be folded off from the yolk the rudiment of one of the two embryonic membranes, the **amnion,** has appeared. A crescentic *amniotic fold* (Fig. 190 A, and 197, A, *am. f'*) arises in front of the head end of the embryo from the region of the pro-amnion: it consists at first of ectoderm only,

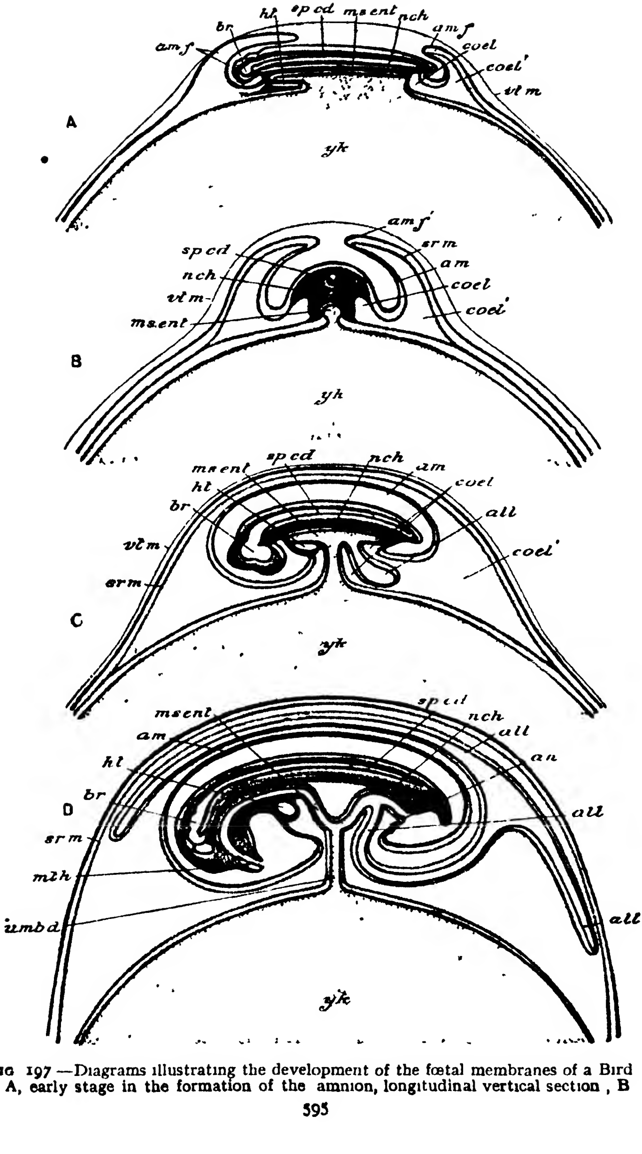


FIG 197 —Diagrams illustrating the development of the fœtal membranes of a Bird A, early stage in the formation of the amnion, longitudinal vertical section , B

slightly later stage, transverse section; C, stage with completed amnion and commencing allantois, D, stage in which the allantois has begun to envelop the embryo and yolk-sac The ectoderm is represented by a blue, the endoderm by a red line, the mesoderm is grey.

all allantois; *all'* the same growing round the embryo and yolk-sac, *am* amnion, *am f* amniotic fold; *an* anus; *br* brain; *cœl.* cœlome; *cœl'.* extra-embryonic cœlome; *ht* heart; *ms ent* mesenteron, *mth* mouth; *nch.* notochord; *sp cd* spinal cord; *sr m* serous membrane, *umb d* umbilical duct; *vt m.* vitelline membrane; *yk* yolk-sac. (Reduced from Parker and Haswell's *Zoology*)

the mesoderm not having yet spread into the pro-amnion. The fold is soon continued backwards along the sides of the body (Fig. 197, B) and a similar fold appears round the tail end (A), but in these regions (*am. f*) it consists from the first of ectoderm *plus* the parietal layer of mesoderm, *i.e.* it is a fold of what may be called the embryonic body-wall or *somatopleure* (p. 567). Its cavity is a prolongation of the space between the parietal and visceral layers of mesoderm—*i.e.* is an extension of the extra embryonic cœlome.

The entire amniotic fold gradually closes in above (Fig. 197, C) forming a double-layered dome over the embryo. Its inner layer, formed of ectoderm internally and mesoderm externally, is the *amnion* (*am*, and Fig. 190, *am'*), the cavity enclosed by which becomes filled with a watery *amniotic fluid*, serving as a protective water-cushion to the contained embryo. Its outer layer, formed of ectoderm externally and mesoderm internally, is the *serous membrane*, sometimes spoken of as the *false amnion* (*sr. m*, *am"*): this comes to lie just beneath the vitelline membrane (p. 551), with which it subsequently fuses.

The second of the embryonic membranes, the **allantois,** is developed as an outpushing of the ventral wall of the mesenteron near its posterior end (Figs. 197, C, *all*, and 191), and consists, therefore, of a layer of visceral mesoderm lined by endoderm (*splanchnopleure*, p. 567). It has at first the form of a small, ovoid sac having the precise anatomical relations of the urinary bladder of the frog. Increasing rapidly in size, it makes its way, back-

wards and to the right, into the extra-embryonic cœlome, between the amnion and the serous membrane (C, D). Allantoic arteries pass to it from the dorsal aorta, and its veins, joining with the vitelline veins from the yolk-sac, take the blood through the liver to the heart (p. 587). Next, the distal end of the sac spreads itself out and extends all round the embryo and yolk-sac (D, *all'*), fusing, as it does so, with the serous and vitelline membranes, and thus coming to lie immediately beneath the shell-membrane It finally encloses the whole embryo and yolk-sac, together with the remains of the albumen, which has, by this time, been largely absorbed (Fig. 197, D). The allantois serves as the embryonic respiratory organ, gaseous exchange readily taking place through the porous shell; its cavity is an embryonic urinary bladder, excretory products being discharged into it from the kidneys.

At the end of incubation the embryo breaks the shell by means of a little horny elevation or *caruncle* at the end of the beak. By this time the remainder of the yolk-sac has been drawn into the cœlome, and the ventral body-walls have closed round it. On the shell being broken the allantois gradually shrivels up, respiratory movements begin, the aperture in the shell is enlarged, and the young bird is hatched and begins a free life.

In the higher Mammalia the allantois takes on a further important function. The relations of the amnion and allantois in the rabbit are essentially similar to those described above in the case of the bird. But the later history of the allantois is widely different, owing to the modifications which it undergoes in order to take part in the formation of the **placenta,** the structure by means of which the fœtus receives its nourishment from the walls of the uterus, with which the blastocyst (p. 573) first becomes adherent over the future placental area by the proliferation of the cells of its outer

layer (*trophoblastic ectoderm*) in this region, which forms irregular processes extending into the thickened mucous membrane on the dorsal side of the uterus (Fig. 198, *e'*). As the embryo develops, it sinks down-and causes the vascular " yolk-sac " or umbilical vesicle (*ys*) to be doubled in and take on a flattened form (Figs. 199,

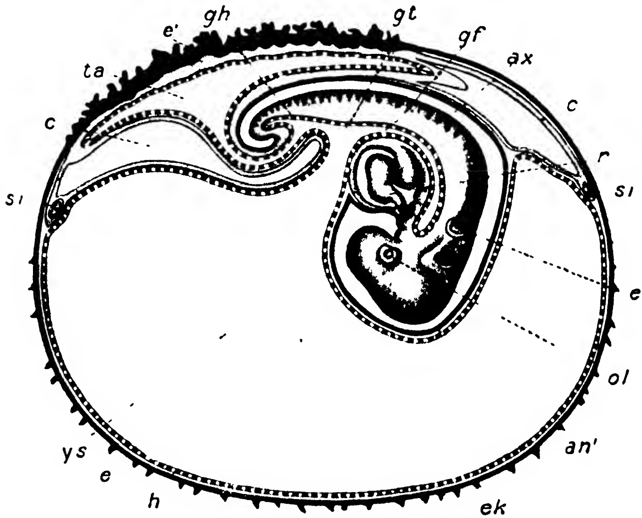


FIG 198.—A Rabbit embryo and blastodermic vesicle (" yolk sac ") at the end of the tenth day The embryo is represented in surface view from the right side, the course of the enteric canal being indicated by the broad dotted line, the blastodermic vesicle is shown in median longitudinal section The greater part of the tail has been removed (× 7½)

an'. pro-amnion, *a x*. cavity of amnion, between the inner or true amnion and the embryo, *c* extra-embryonic portion of cœlome; *e* trophoblastic ectoderm, *e'*. thickened part of *e* by which the blastodermic vesicle is attached to the uterus, and from which the development of the fœtal part of the placenta proceeds, *ei*. auditory vesicle, *ek* ectodermal villi, *gf*, *gt*, *gh* enteron, *h* endoderm; *ol* eye; *r*. heart, *si* circular marginal vessel of area vasculosa, *ta* cavity of allantois, *ys* cavity of " yolk-sac " (From Marshall, in part after Van Beneden and Julin)

ds, 198 and 200, *ys*) : this early becomes attached to the mucous membrane of the uterus, and represents a *vitelline* or *yolk-sac placenta* such as occurs in some viviparous

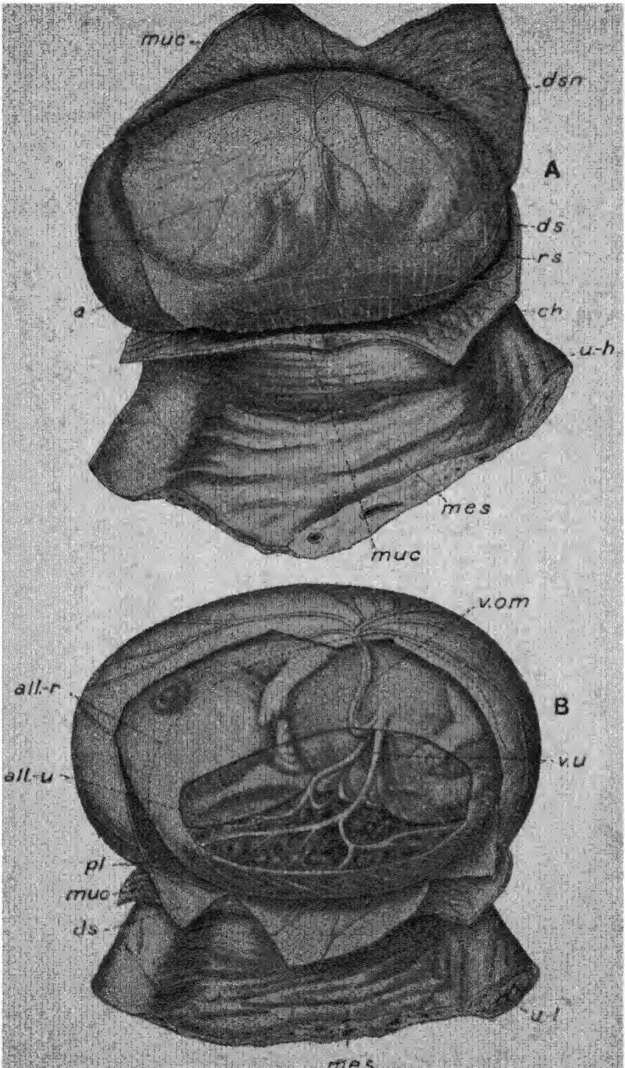


FIG 199.—Portion of the uterus of a Rabbit containing an advanced fœtus (× ⅔) In A, the uterus has been opened and its wall reflected, and part of the " yolk

sac" (umbilical vesicle) cut away (left of the figure) to show the underlying amnion In B, part of the uterine wall has been removed and part of the yolk-sac and amnion cut out so as to expose the fœtus and placenta.
a amnion, *all.r.* dotted line indicating margin of allantois (compare Figs. 210 and 212, *ta*); *all.u* line along which the allantois is reflected over the placental region, *ch* chorion, *ds* yolk-sac; *dsn* point at which the umbilical vessels branch out from the umbilical stalk, *mes* mesentery of uterus, *muc* mucous membrane of uterus, *pl* fœtal surface of placenta covered by the distal wall of the allantois; *rs* circular marginal vessel of area vasculosa of yolk-sac; *u-h.* undilated narrow portion of uterus between two fœtus-containing swellings; *u-l.* lumen of uterus; *v om* vitelline vessels; *v u* allantoic vessels (From Grosser's *Vergl Anat u Entwick. geschichte der Eihäute und der Placenta*)

dogfishes; but its nutritive function in the mammal is of only minor importance.

The *fœtal part* of the placenta is formed from the outer layer of the amnion (serous membrane) in a limited disc-shaped area covered by the thickened part of the trophoblastic ectoderm where the distal portion of the allantois coalesces with it (Fig. 198) The membrane thus formed (*chorion*) develops vascular processes or septa—the *chorionic villi,* which are received into depressions—the *uterine crypts*—in the thickened placental folds of mucous membrane on the dorsal wall of the uterus which constitute the *maternal portion* of the placenta (Figs. 198 and 199). The fœtal portion of the placenta with its villi is supplied with blood by the allantoic vessels, and the blood-supply of the uterus is at the same time greatly increased: the fœtal and dilated maternal capillaries and sinuses are thus brought into intimate relation with one another in the placenta, being only separated by thin layers of epithelium: diffusion can thus take place between them, nutrient matter and oxygen diffusing from the blood of the mother into that of the fœtus, while excretory substances pass from the blood of the fœtus into that of the mother.

The disc-shaped or *discoidal* placenta of the Rabbit is of the type termed *deciduate,* its villi being so intimately connected with the uterine mucous membrane that a part of the latter comes away with it at

birth in the *decidua*, or afterbirth, which is attached to the newly-born young by the *umbilical cord*, consisting

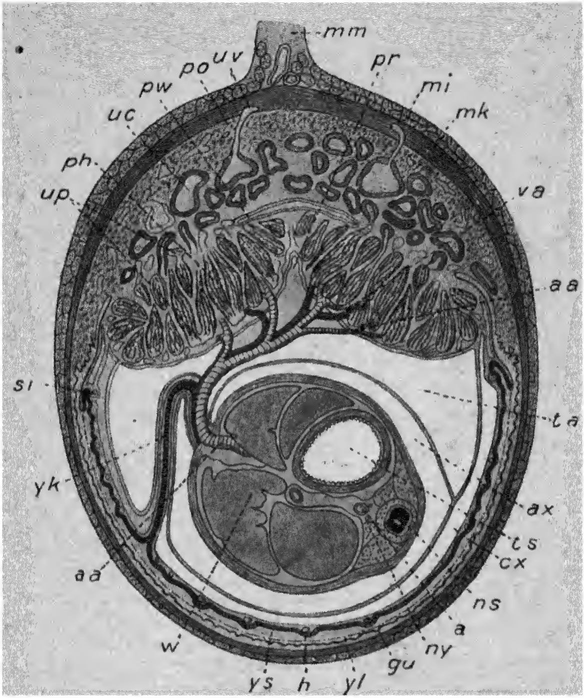


FIG 200.—A transverse section across the uterus and the contained embryo of a Rabbit at the end of the nineteenth day The embryo is cut transversely about the middle of the body, the section passing through the "yolk stalk" and allantoic stalk (× 2⅔)

A, dorsal aorta, *aa.* allantoic artery; *a x.* cavity of amnion, between the inner or true amnion and the embryo; *cx* space between the inner and outer layers of the amnion; *gu* uterine glands, *h* endoderm of upper or vascular wall of "yolk-sac" (umbilical vesicle); *mi*, *mk* outer or longitudinal, and inner or circular muscles of wall of uterus, *mm* mesentery of uterus, *ns* spinal cord, *ny* sympathetic nerve-cord; *ph.* lobule of placenta; *po.* region along which the separation of the placenta occurs at birth; *pr* inter-placental groove; *pw* sub-placental cavity; *si.* circular marginal vessel of yolk-sac, *ta* cavity of the allantois (see Fig 198); *ts.* stomach; *uc.* dilated uterine capillary, with thick perivascular wall; *up* uterine or maternal sinuses of placenta; *uv* blood-vessels of uterus, *va.* allantoic vein; *w* liver; *yk* stalk of yolk sac; *yl.* dotted line representing the lower or non-vascular wall of the yolk-sac, now completely absorbed, *ys* cavity of yolk-sac, continuous with the uterine cavity owing to absorption of the lower wall of the yolk-sac (From Marshall)

of the stalks of the allantois and flattened yolk-sac twisted together (Figs. 198 and 200), in which allantoic and vitelline blood-vessels are passing.

The blood-vessels at the plane of separation of the placenta and uterus are very small, and the uterus contracts so rapidly when the young are expelled at parturition that very little bleeding takes place, and the mucous membrane rapidly undergoes regeneration, ready for the next conception. The cord is gnawed through by the parent rabbit, the blood-vessels being compressed in the process; and it soon shrivels up and comes away at the navel or *umbilicus* which represents the point of connection between the fœtus and the placenta The intra-abdominal portion of the allantois is represented by a cord or ligament, the *urachus*, which connects the navel with the apex of the bladder, so that only a small portion of the allantoic outgrowth persists in the adult, and not the whole of it, as it does in the frog.

PRACTICAL DIRECTIONS

A. A series of models of the development of *Amphioxus* should be examined. Note—

a, the various stages of *segmentation* and the formation of the *segmentation-cavity* (Fig 184, A–G); *b*, the obliteration of the segmentation-cavity during the formation of the *gastrula*, with its *ectoderm*, *endoderm*, and *blastopore* (H, I); *c*, the elongation of the gastrula, the flattening of the surface which will become dorsal, and the position of the blastopore at the posterior end (J); *d*, the formation of the *medullary plate* and *cord*, the *mesodermal segments* and *enterocœles*, and the separation of the latter from the enteron, the walls of these cavities forming the parietal and visceral layers of the mesoderm; and the formation of the *notochord* and the *neurenteric canal* (K—O).

B. In order to follow out the development of the chief organs in the Vertebrata, it is necessary to make a number of serial sections of various embryonic stages. For this purpose chick-embryos (*see below*) are, on the whole, the

most convenient and satisfactory; but if you have not already followed out the instructions given on pp. 224–226, you should not only examine externally the stages in the development of the *tadpole* up to hatching, but also study sections of some of the early stages showing *a*, the *segmentation-cavity* (Fig 69, E); *b*, the *enteron*, *blastopore*, and *yolk-plug* (I); and *c*, the *medullary cord*, *notochord*, *mesoderm*, and *cœlome* (Figs. 69, K, and 70, A and B). Compare with the corresponding stages in Amphioxus

C. A number of fresh, impregnated *fowls' eggs* should be obtained and placed in an incubator at a temperature of about 39·5° C. (103° F.), or under a "broody" hen, first marking each with the date. One or two should be examined each day or oftener for the first four or five days of incubation. Expose the embryo as directed on p. 562, using warm normal (0 75 per cent) salt solution (temperature as above), in order that after the first day the beating of the heart and the circulation of the blood may not be stopped. Remove sufficient of the shell and shell-membrane to expose the entire blastoderm, as well as the embryo proper when developed. Examine with a hand-lens before removing, and then, after carefully cutting through the vitelline membrane with fine scissors around the margin of the blastoderm, the latter should be floated off in a watch-glass, and the covering vitelline membrane removed by the aid of a needle—an operation which requires considerable care in the early stages. Fix with corrosive sublimate, and after about half an hour wash in water and preserve in increasing strengths of alcohol up to 90 per cent (see p 145)

Two specimens of each stage should be preserved, one for examining entire, and the other for sectioning[1]; they should subsequently be stained entire with borax-carmine or hæmatoxylin, the one mounted in Canada balsam on a slide after treating with absolute alcohol and xylol or oil of cloves, and the other imbedded in paraffin (see p. 146). Serial sections of each embryo should be mounted in order, after smearing the slide with collodion and oil of cloves or glycerine and albumen (p 147).

Sketch typical preparations of the various stages, both *entire* embryos and *sections*.

[1] The early stages are difficult to prepare, and the most important of those referred to below are *from the end of the first to the third day of incubation*. As the medullary groove only closes gradually from before backwards in the body-region, sections showing different stages in the development of the central nervous system may be obtained from the same embryo at these stages.

I. *External characters.*

1. *Unincubated egg.* Segmented blastoderm (Figs. 181, 185, D).

2. *First day of incubation* (18–20 *hours*). Note the *area pellucida, area opaca, primitive streak,* and *medullary plate* (Fig 185, E)

3. *End of first day* (*about* 24 *hours*). Note the *area pellucida, area opaca, pro-amnion, head-process* and *medullary groove, primitive streak* and *groove,* and the small number of *mesodermal segments,* which increase in number from before backwards (compare Figs. 185, E, and 191, A)

4. *Second day.* Note—*a,* that the blastoderm has further increased in size, that *blood-vessels* are apparent in the *area opaca,* and that the head end of the embryo has become raised above the yolk and is beginning to be covered by the *head-fold* of the *amnion ; b,* the *medullary folds,* which meet in the middle line except at the posterior end, in front of the primitive streak, while in front the *medullary cord* thus formed has become swollen to form the *vesicles of the brain,* and the *optic vesicles* are seen standing out right and left from the fore-brain ; *c,* the *auditory pits,* one on either side of the hind-brain region ; *d,* the increase in number of the *mesodermal segments ; e,* the *heart* and main *vitelline veins* (Figs. 187, A, 188, 189 and 190, A)

5. *Third day.* Note—*a,* the further extension of the *area vasculosa* and its blood-vessels and the folding off of the embryo from the rest of the blastoderm investing the yolk ; *b,* the *amnion ; c,* the *head,* which is proportionately very large, has become twisted over—so that its right side is now uppermost, and has undergone *flexure,* the prominent mid-brain being now at the anterior end ; observe the *cerebral hemispheres* and the *cerebellum* in addition to the other parts of the brain ; *d,* the *visceral arches* and *clefts ; e,* the *olfactory pits, optic cups* and *lens,* and closed *auditory vesicles ; f,* the *mesodermal segments ; g,* the S-shaped *heart, arterial arches, dorsal aorta,* and *vitelline veins* (Figs. 189, B, and 190, B).

6. *Fourth to sixth days.* Note—*a,* the advances in the parts mentioned above, including the further extension of the area vasculosa over the yolk, the narrowing of the yolk-stalk, the flexure of the whole embryo, and the amnion ; *b,* the budding *fore-* and *hind-limbs ; c,* the *allantois,* at first a small sac extending from the ventral side of the body and gradually increasing in size (Figs. 190, C, and 191, C). By the sixth day, the embryo can be recognised as that of a bird from the characters of the fore-limbs (wings), hind-

limbs, head, etc.: feather-rudiments cannot be recognised until the ninth day.

7. *A few further stages* should be examined (compare Fig. 191, D), especially that just before hatching, at the end of the third week of incubation, when it will be found that the albumen has become absorbed, and the very vascular allantois will be seen all round the egg directly under the shell, its stalk entering the body at the umbilicus; the remains of the yolk-sac have been withdrawn into the body at the same point. Note also the *neb* or *caruncle* on the beak, used for breaking the egg-shell at hatching.

II. *Transverse sections.*

1. *Unincubated egg*[1] Note the *ectoderm* and the *lower layer cells* (Fig. 185, F).

2. *First day of incubation.* Less difficulty will be experienced if you select embryos towards the end of the first day (20–24 hours). Distinguish between the *ectoderm*, *endoderm*, and *mesoderm*. Note—*a*, the formation of the *medullary groove* and *folds*; *b*, the *primitive streak* and *groove*; *c*, the *notochord* (Figs 185, G, and 187).

2. *Second day.* Note—*a*, the parts mentioned under first day, tracing the series of sections through the whole embryo; *b*. the gradual meeting of the medullary folds to form the hollow *medullary cord*; *c*, that anteriorly the head has become folded off from the yolk, so that the enteron in this region forms a closed tube, lined all round by endoderm; *d*, the *cerebral vesicles*, and the *optic vesicles* arising from the fore-brain, the *lens* and the *auditory pits* from the ectoderm; *e*, the *mesoderm*, consisting on either side of dorsal *mesodermal segments* and of a ventral portion, split into *parietal* and *visceral layers*, with the *cœlome* between them—the former layer, with the ectoderm, constituting the body-wall or *somatopleure*, and the latter, with the endoderm, the wall of the enteron, or *splanchnopleure*; *f*, the *heart*, *vitelline vessels*, paired *aortæ*, and *cardinal veins* (Figs 190 and 189, A).

3. *Third day.* Note—*a*, the parts mentioned above under the first day, and their further development, including the *flexure* of the brain, formation of the *optic cup* or *secondary optic vesicle*, *choroid fissure*, and the closure of the *auditory pits*; *b*, the *mesonephric* (*Wolffian*) *ducts* on the dorsal side of the cœlome; *c*, in the pharyngeal region, the relations of the *visceral arches* and *clefts* and of the *arterial arches*; *d*, the somatopleuric *amniotic folds*, and the way in which they meet to form the *serous membrane* ("*false amnion*") and the *true amnion* and *amniotic cavity*. (The *allantois* arises

[1] *See* note about early stages on p. 603.

from the hinder part of the splanchnopleure on the fourth or fifth day).

(Figs. 190, B, C, 191, 192, 193, and 197.)

D. 1. If you have been fortunate enough to obtain some *blastocysts* of the *rabbit* (see p. 573), examine them carefully with a lens, and note the outer layer of cells (*trophoblast*) and the smaller mass (*embryonic area*) attached to the former on the inner side of the vesicle at one pole (Fig. 186, E)

2. Obtain, either fresh or preserved, a gravid uterus of the rabbit or rat containing advanced embryos. Slit open each swelling of the uterus carefully on the ventral side, and note—*a*, the flattened *umbilical vesicle* ("yolk-sac"); *b*, the *fœtus*, enclosed by the thin, transparent *amnion*, containing a fluid; *c*, the vascular *discoid placenta*, closely attached to the dorsal side of the uterus, and connected with the *navel* or *umbilicus* of the fœtus by a vascular *umbilical stalk*, consisting of the stalk of the allantois and that of the umbilical vesicle twisted around one another (Figs. 198 and 200).

3 Sections should be made through the uterine wall and placenta in order to make out the relations between the maternal and fœtal portions of the placenta (Fig. 200).

CHAPTER XII

EVOLUTION

What Evolution means.—The student of Biology is struck with the great diversity exhibited by animal and vegetable forms now existing on this earth. He is no less struck with the resemblances in greater or lesser degree which various forms bear to one another and the marvellous adaptation which the parts of an animal or plant show to the functions which they have to perform. The phenomena of diversity in the organic world, resemblances shown by the animals and plants belonging to particular groups, and the numerous adaptations exhibited by individual organisms are all due to the fact that the forms now living on this earth did not appear as such, but were *evolved* through gradual modifications taking place during many generations, in the forms that lived before. The doctrine of Organic Evolution teaches us that species or kinds are not immutable, but are subject to changes whereby one may give rise to another, and that all existing species are the more or less modified descendants of pre-existing ones. Out of simple beginnings, when in the course of ages the earth was fit for the existence of life on it, life began, and by a continual process of evolution there have come into existence not

only all the marvellously adapted forms of animal and plant life that we see to-day, but also those which have existed in the past, and some of which have left their fossil remains behind. All men of science and most other thinking men are now convinced of the truth of evolution in the inorganic as well as the organic world. Whatever differences may exist as regards the theories which have been propounded from time to time, to explain how evolution takes place, the fundamental conception of evolution is the accepted creed of all biologists, and serves as the basis on which all their attempts at natural classification depend.

Yet a student of science may not feel inclined to accept such a bold generalisation, and we shall therefore briefly indicate in the following paragraphs the nature of the evidence in support of the doctrine.

Anatomical Evidence.—(1) The mere fact that we are able to *classify* the animals, and to express their resemblances and differences by placing them in phyla, classes, orders, etc. (see p. 234), which are more or less closely related to each other, is a strong indication in favour of a doctrine of descent. All the Chordates show certain common features of structure (see p. 414), and this is so because in the remote past they must have had a common origin. Again, although all the Chordates can be placed in certain definite classes, each class shows many resemblances with one or the other of the remaining classes, *e.g.*, Amphibia with the Fishes, Reptiles with Amphibia, Birds and Mammals with the Reptiles. On data afforded by Comparative Anatomy alone, the inference is irresistible that Amphibia are derived from Fishes, Reptiles from Amphibia, and both Birds and Mammals from Reptiles independently of each other. These inferences are given a vivid expression by

illustrating the mutual relationships in the form of genealogical trees, as in the following diagram :—

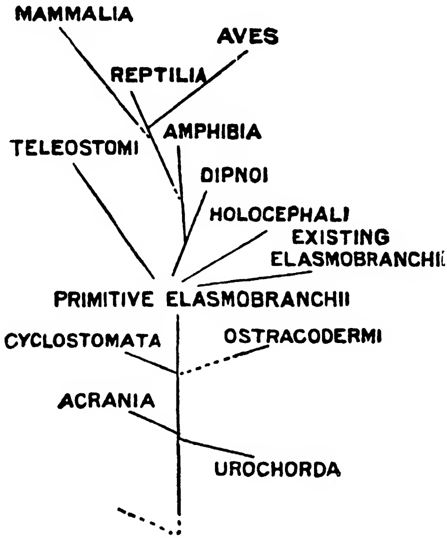


FIG 201.—Diagram illustrating the Mutual Relationships of the various classes of the Phylum Chordata (From Parker and Haswell's *Zoology*) Adelochorda, Urochorda, Cyclostomata, Ostracodermi, Holocephali are names of groups which have not been referred to in this book Acrania = Cephalochorda

From the above we must not fall into the error of supposing that Amphibia are believed to have been descended from any existing forms of fish or conversely that any existing forms of fish would or could evolve into another set of amphibian creatures. It cannot be too strongly insisted upon that in the majority of cases it is useless to seek for the ancestors of any animal among existing forms. As far as we know, most living species are culminations—terminal branches of the great tree, not leading directly to any other form, but connected only at the fork of a branch. Of all living creatures, Amphibia no doubt show greatest resemblance to the Dipnoi (or *lung-fishes*), but it would be a mistake to think that they are descended from the Dipnoan fish existing to-day. In the tree, both the branches are connected only at the fork, and both Amphibia and

Dipnoi may be said to have evolved along different lines from a group of more primitive ancestors, which must have possessed the characters which are now the common heritage of both.

(2) We are often able to arrange existing organisms in progressive series, of which the extremes are connected by intermediate forms. Not only are the *connecting links* found between closely related species, but sometimes between the larger groups of the animal kingdom as well. For example, the Reptilia and the Mammalia as they exist to-day are two distinct classes of the Vertebrata, each of them having a clearly marked set of characteristic features. Yet, as mentioned in a previous chapter (p. 511), a small group of mammals known as Prototheria, and including the duck-billed mole (*Ornithorhynchus*, Fig. 167) and the spiny ant-eater (*Echidna*), are found in Australia and the neighbouring islands, and are of very great zoological interest. These animals possess hairs and suckle their young ones, entitling them to be placed among the mammals, but they also possess certain other characters in which they differ from the ordinary mammals and resemble the reptiles. For example, they lay large eggs with abundant quantity of yolk, the alimentary and the urinogenital ducts open into a cloaca, and the shoulder-girdle consists of separate clavicle, coracoid, epicoracoid and scapula bones as in the reptiles, and like the latter there is a curious T-shaped bone known as the interclavicle, which is not found in other mammals. Such animals are the relics of the past, indicating the path along which the more highly organised groups may have progressed, at least for part of their journey, in their onward march of evolution.

(3) A common type of structure is met with, running through a whole series of forms, in which the same

essential parts, though often differently modified in accordance with differences in functions, are to be found in the same mutual relations. In all classes of the Vertebrates except the Pisces, there are two pairs of limbs, which differ greatly in form and structure according to the mode of life of the animals possessing them. In land vertebrates, whether amphibians, reptiles or mammals, the body is carried on all fours, both pairs of limbs serving as legs. In birds, on the other hand, the fore-limbs are modified into wings to enable them to fly in the air, and the hind-limbs alone support the body, while standing or moving about. The fore-limbs are also modified for flight, though in somewhat different manner in the bats and the extinct flying reptiles known as pterodactyls (see Fig 176). In vertebrates living in water, for example, turtles among reptiles and whales and seals among mammals, the limbs are modified into paddles for swimming in water. Yet these structures, however different they may be in their general form and appearance, are found on closer examination to be built on essentially the same plan, *viz.*, the pentadactyl or five-fingered type of appendage. The wing of the Bird and of the Bat, the flipper of the Whale, the foot of the Horse, and the hand of Man are all *homologous organs*, and will be found to contain the same bony elements (compare Figs. 173, 174, 175, and 176).

The hoofed mammals, or Ungulata, afford examples of series of forms exhibiting a gradual reduction in the number of digits, accompanied by a gradual lifting of the hinder part of the foot from the ground, till we get to those cases in which the animal is seen to rest and walk on the tips of one or two toes only. Among the Perissodactyla, we find the tapir with four fingers in the manus and three toes in the pes, the rhinoceros with

three digits in each, and the horse with only the middle (third) digit in both manus and pes, with vestiges of Nos. II and IV as the functionless "splint-bones" which lie on either side of the greatly elongated metacarpal or metatarsal of the middle digit (see Fig. 174). Among the Artiodactyla, are to be found the hippopotamus, with four well-developed digits in each foot; the pig, with four digits in each foot, the two outer ones of which

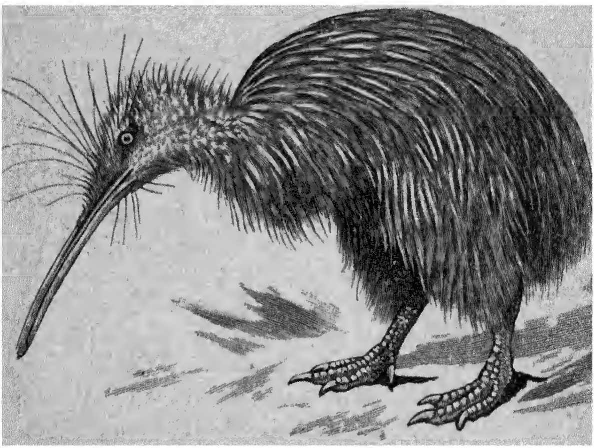


FIG. 202—The KIWI—*Apteryx*

are greatly reduced; the deer, with the same showing further reduction; the sheep and oxen, in which the second and fifth digits are reduced to small nodules of bone, and, lastly, the camels, in which all traces of the two outer ones have completely disappeared and only two toes are found in each foot (see Fig. 175).

(4) In many cases what is a functionally active and important part in one animal is found only as a mere vestige, apparently quite useless, in an allied form. One of the most instructive examples of these *vestigial organs*

is to be found in the flightless bird known as Kiwi or Apteryx of New Zealand, which is now rapidly becoming extinct. Its body is covered with coarse feathers which are so small as to look almost like hair, and the wings are so much reduced and concealed under the general plumage, that the bird appears to be without wings. The much-reduced structures are of no use as organs

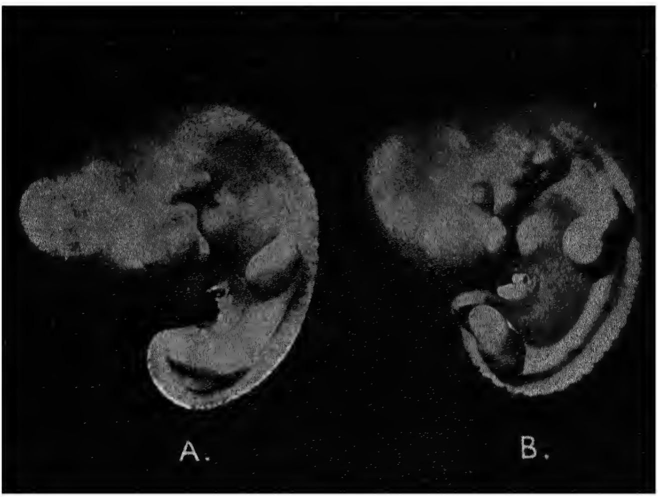


Fig 203—A Chick embryo of about 5½ days, × 5 B Rabbit embryo of about 13 days, × 5. In both cases the fœtal membranes and yolk-sac have been removed. (From photographs). (After Dendy)

of flight Yet this vestige still possesses essentially the same bony framework and the same muscles, though in a greatly reduced condition, as the complete and functional wing of the Pigeon. Numerous examples of such vestigial organs could be given. In man himself there are many vestigial structures. At the lower

end of the vertebral column is found the coccyx, which represents a much-reduced tail, which in rare cases is accompanied by vestiges of muscles which in other animals are used for wagging the tail. The hair on the chest and other parts of the body are also a complete hairy coat, such as is now possessed by the apes. The external ear is a vestige of movable ears, and there are the same muscles in connection with it which other animals use for moving their ears up and down. The only rational explanation that can be given for the occurrence of these vestigial and useless organs is that they are inherited from remote ancestors in which those organs were functional.

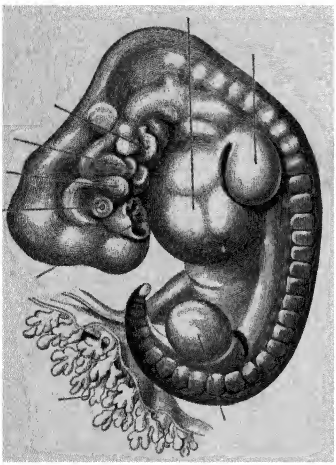


Fig. 204—Human embryo, between twenty-seven and thirty days old. (After His, from *Gray's* "*Anatomy*". Longman's, Green, & Co Ltd)

Embryological Evidence.—The embryos of animals of one great class or even a phylum present a great resemblance to one another, and the nearer the adult forms are in structure, the closer, usually, is the similarity in their developmental stages. If series of embryos belonging to different vertebrate types are examined, the later stages would be found to differ considerably, but the earlier corresponding stages show such a close resemblance that in many cases it is difficult for even an experienced embryologist to distinguish between them (compare Figs. 203 and 204).

Evidence of an allied character is afforded by the fact that in the course of its development one of the higher animals sometimes appears to exhibit in successive stages features permanent in forms lower in the scale. We have already seen how a frog in its early condition as a tadpole larva is to all intents and purposes a fish (p. 237), and explained it with reference to the recapitulation theory; which means that the successive stages in the development of the individual animal (*ontogeny*) tend to reproduce, though in a very abbreviated and often greatly modified shape, the stages through which the group has passed in the course of its evolution from lower forms (*phylogeny*). In the case of the tadpole, however, it might be argued that it possesses gill-clefts, gills, and fish-like circulation, because for the time being it is an aquatic creature, and not necessarily because a frog is descended from fish-like ancestors. But what of the birds and the mammals, where the embryo is never exposed to an aquatic environment, but always develops protected within the egg-shell or in the mammals within the uterus of the mother? It is indeed truly remarkable that the embryo of a Mammal presents at an early stage visceral arches and clefts of a Fish, and has a blood-circulation in accordance with this; while at a later stage it exhibits in these particulars some resemblance to an Amphibian, later on to a Reptile, and only when development is further advanced takes on its special mammalian characters

Certain stages of development are common to all metazoan animals, and the inference is therefore drawn that these must represent ancestral stages through which the Metazoa as a whole passed in the dim youth of their evolutionary career. Every individual starts its existence as a single cell, and immediately after fertilisation the ovum begins to segment into two, then four, then

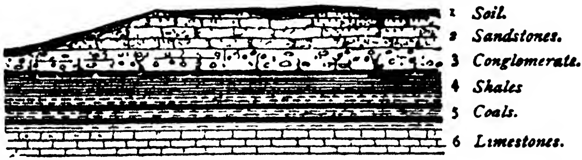
eight, sixteen, and so on, individual cells which remain attached to one another, forming a solid aggregate known as the morula. Further segmentation produces a hollow blastula, the cavity within being the segmentation cavity or blastocœle. The next stage is that known as the gastrula, in which the embryo becomes two-layered, with a full differentiation into two distinct tissues composed of cells, the primary requisite of a metazoan animal. This is generally the result of an inpushing or invagination of the cells at one pole of the blastula into the blastocœle, more or less obliterating it (see Fig. 196). Various methods of gastrula formation are found in different animals, but the fact remains that up to this point all metazoan development, whatever the ultimate result, follows the same or strictly parallel roads. "Now we come to the parting of the ways, when the least related go each their several roads, which ultimately branch into as many byways as there are forms of life. The nearer of kin the creatures are, the later is their embryonic divergence." (Lull.)

Palæontological Evidence.—The study of existing remains of past life on this earth called fossils, is known as Palæontology. Let us inquire what evidence has this study to offer in favour of the doctrine of evolution?

The materials of which the solid crust of the earth is made up, *i.e.*, masses of mineral matters of various kinds such as granite, sandstone, coal, clay, chalk, are, in the language of geology, all spoken of as rocks. The rocks are divided into two chief classes, viz. *igneous* and *sedimentary*. The former include rocks like granite and basalt, which were formed as the result of the cooling of molten matter, of which the earth was probably at one time composed. The latter were formed by the slow accumulation of material derived from the wear

and tear of other rocks or from organic remains, and were deposited layer after layer under water. The sedimentary rocks, from their occurring in regular layers or strata, are also known as *stratified rocks*, and limestone, sandstone and coal are examples of such rocks. Gravel, sand or mud, laid down in layers,

A



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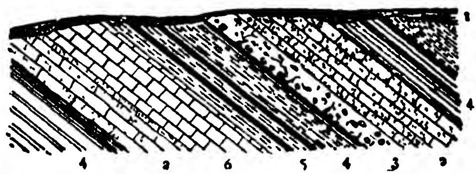

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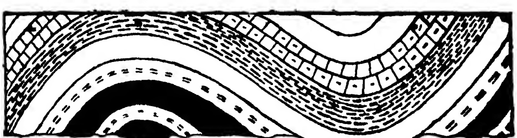

FIG. 205 —Stratified Rocks (After Dennis Hird)

became in course of time hardened by the weight of subsequent deposits, and strata are therefore found to be superimposed on one another. Sometimes they lie almost flat, as in A of Fig. 205, but, as the result of volcanic action and irregular contraction of the earth's crust, the layers are often found to be tilted at various angles (as in B) or even curved or contorted (as in C).

Rocks originally deposited on the bed of the sea have been raised up to form dry land or raised so far above sea-level as to form mountain ranges. The occurrence of fossils of marine forms in the deposits forming these mountain ranges is an unmistakable evidence that these mountains were at one time the bottom of the ocean. The igneous or unstratified rocks, for they have no regularity of position or arrangement, pierce through the layers of other rocks, or even overlie them in broad, vast masses (Fig. 206, *b*). There is still a third kind of rock, called the metamorphic or altered rocks. They are formed out of stratified or unstratified rocks, under

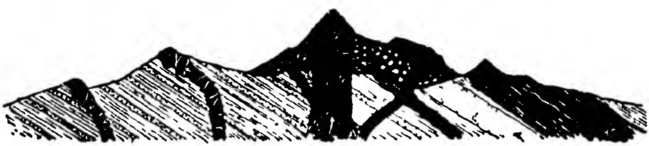

FIG 206.—*a* stratified, *b* unstratified rocks (After Dennis Hird)

the very great heat and pressure to which they have been exposed. The common roofing-slate is a good example of this kind of rock.

For the purposes of our inquiry, the stratified rocks only are important, as the unstratified rocks contain no fossils. It is obvious that in any series of stratified rocks, the more superficial layer is of a later period than the one below it. But different kinds of deposits are not found to occur in the same order in different parts of the earth. The geologists have, however, compared the series of stratified rocks found in different parts of the world with one another, and, by the aid of the assemblages of fossils which they contain, recognised a number of well-defined epochs in the geological history

of the earth. Right below the series of stratified rocks is a vast thickness of rocks, in which no fossils have been met with. This thickness signifies a period of time, extending over millions of years, probably equalling in duration all the subsequent geological periods put together. Of the evolutionary history during this vast pre-Cambrian epoch nothing is known. These rocks were probably originally sedimentary and contained the most valuable evidence concerning the evolution of the different phyla of the animal and the vegetable kingdoms, but owing to the action of pressure and heat, their character has been profoundly altered and all the fossils originally contained in them destroyed. All the subsequent deposits are still found to contain organic remains to a greater or less extent, and the countless millions of years of earth's history signified by them are divided into three great eras, viz. palæozoic or primary, mesozoic or secondary, and cainozoic or tertiary. Each of these is subdivided into a series of epochs, as shown in the table on the next page, in which are also mentioned the relative duration of each as indicated by the estimated thickness of the stratified rocks.

If evolution has taken place, the uninitiated student may feel inclined to think that we ought to be able to find in the rocks belonging to the various geological formations a complete series of animal and plant remains representing all the stages in the evolution of the highest forms from the lowest ones. Beginning with those strata in which evidence of life first appears, we ought, it might be supposed, to be able to trace upwards, through all the series of fossil-bearing strata, continuous unbroken lines of descent showing the gradual evolution of all the various forms of animal and plant life. If such a complete geological record existed, it would undoubtedly be the

FIG. 207.—GEOLOGICAL TIME-SCALE, AS INDICATED BY THE STRATIFIED ROCKS. (After Dendy.)

Eras	Epochs, with relative duration indicated by thickness of stratified rocks.	Range in Time of Animal Groups. Invertebrates	Fishes.	Amphibians	Reptiles	Birds	Mammals.	Man.
Cainozoic or Tertiary.	Recent and Pleistocene 4000 feet.							
	Pliocene 18000 feet.							?
	Miocene 14000 feet.							
	Oligocene 12000 feet							
	Eocene 20000 feet.							
Mesozoic or Secondary.	Cretaceous 44000 feet.							
	Jurassic 8000 feet							
	Triassic 17000 feet							
Palæozoic or Primary	Permian 12000 feet.							
	Carboniferous 29000 feet.							
	Devonian 22000 feet.							
	Silurian 15000 feet.							
	Ordovician 17000 feet.							
	Cambrian 26000 feet.							
	Pre Cambrian (extent unknown).							

most conclusive direct evidence of the course which evolution has actually taken. But that is not the case, and the *imperfection of the geological record* is due to many causes, which are thus summed up by Dendy:—

"It must have been imperfect when first laid down, for the great majority of animals disintegrate and pass away without leaving any recognisable remains behind them at all. In most cases it is only hard skeletal structures that have any chance of being preserved. Bodies composed entirely of soft tissues, such as jelly-fish and many worms, are rarely represented by fossils. Even hard structures, such as animal skeletons, will only be fossilised if they happen by some fortunate chance to find their way to some place where rock formation of a suitable kind is going on. The remains of land animals may be carried by rivers to some sea or lake and buried in a suitable accumulation of mud or sand, but it is more likely that they will not. Marine animals, provided they have hard skeletons, have, of course, many more opportunities of attaining a lasting monument, and we often find great thicknesses of rock, such as chalk and limestone, composed almost entirely of their remains.

"Even when the record has been successfully established, however, it is liable to destruction by various agencies. The rocks containing it may be lifted above sea-level and planed right away by sub-aerial denudation, or they may be sunk so far beneath later accumulations as to be profoundly altered by the action of heat and pressure, by which means any fossils which they contain may be completely destroyed. Then, again, we must remember that only a relatively small proportion of the earth's crust is accessible for investigation. Deep-lying rocks may be brought to the surface by upheaval, and denudation of overlying strata, or they may be reached

by deep mining, but we know practically nothing of the strata which now lie beneath the bed of the sea, and even the dry land has only been tentatively scratched by inquisitive man in a few places."

As mentioned above, the earlier portions of the record have apparently been completely destroyed, so that already in the Cambrian epoch highly organised invertebrate animals belonging to diverse phyla are found to have been in existence, but from this period onwards the geological record affords abundant evidence to show that the higher groups of animals and plants appeared on the earth in the order which definitely supports the view, that the higher forms must have evolved from forms of a lower and more generalised type that existed before them. To illustrate this point let us take the Vertebrata, the different classes of which seem to have evolved within post-Cambrian times.

There is no evidence of the highest class—the Mammalia—earlier than the Triassic period of the Mesozoic era. Birds appear for the first time in deposits of Jurassic age, and are therefore more recent than the oldest mammals; but birds are very highly specialised vertebrates, and both classes seem to have evolved from lower forms independently of each other. Reptiles extend as far back as the Permian. Amphibia begin to occur in the Lower Carboniferous; whilst typical fish appear first in the passage beds between the Upper Silurian and the Lower Devonian. Within each of these classes a progress is usually traceable from older, more generalised types, along diverging lines, to the various specialised forms existing at the present day. In certain cases among the mammals a number of closely related stages have been discovered from different formations, which taken in their chronological order show a gradually increasing specialisation of structure. Thus the ancestry of horses, elephants, camels, and many other families

has been fairly satisfactorily worked out. One of the best known examples is that of the horse, and may be referred to very briefly here. On comparing the foot of the horse with its single toe with that of other Ungulates in which three or five toes are met with (Fig. 174), the inference is natural that the single-toed limb must have arisen from the primitive pentadactylic type by the gradual reduction and disappearance of all the digits except the middle one. A large number of fossil remains of horse-like animals have been found in the tertiary formations of Europe and America, and a very complete series of stages in the evolution of the modern horse discovered, which actually show this reduction and disappearance of the digits and thus confirm the inference drawn from the study of comparative anatomy. Largely through the efforts of Marsh a collection of fossil forms was assembled together which proved the first documentary record of the evolution of a race. This classic collection was studied by Huxley, who pronounced it to be "demonstrative evidence of evolution." The figure on the next page is reproduced from Huxley's works, and illustrates the important structural peculiarities of a number of fossil forms which are considered to form the fossil pedigree of the modern horse. The gradual reduction and suppression of lateral digits both in the fore- and the hind-limb through this series of forms will be noticed at once, and, what is no less interesting, the gradual reduction of ulna in the fore-limb and of fibula in the leg, and the increasing complexity of the molar teeth has been taking place in the same forms, side by side with the reduction in the number and length of the toes. It will be noticed that the ancestral form met with in the Miocene and termed *Mesohippus* has three toes in front, with a large splint-like rudiment representing the little finger, and three toes behind. The still older *Orohippus*, which comes from the Eocene formation,

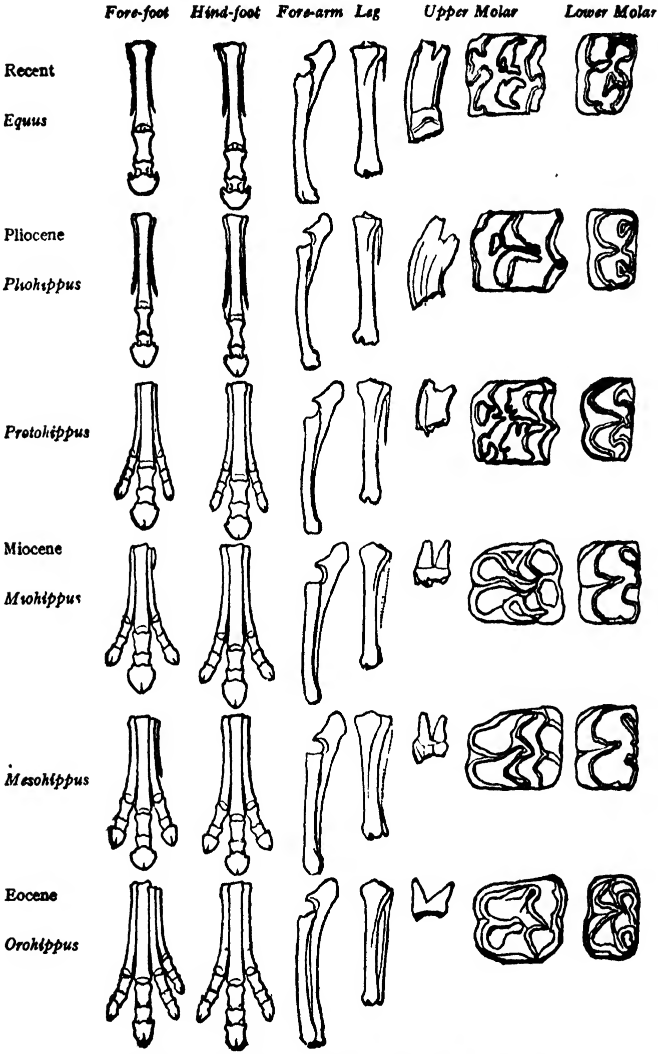

FIG. 208.—Some representative fossil remains which throw light on the ancestry of the Horse. (After Huxley.)

has four complete toes on the front limb and three toes on the hind limb. After examining this series of forms Huxley prophesied that when the still lower Eocene deposits have yielded up their remains of ancestral equine animals we shall find a form with four complete toes and a rudiment of the innermost or first digit in front, and with three digits and a rudiment of the fifth digit in the hind foot, and this anticipation was more than justified only a few months later by the discovery by Marsh of another genus of equine mammals (*Eohippus*) from the lowest Eocene deposits.

It may also be mentioned here that in some cases—notably in the Amphibia, Reptilia, and Aves—the orders which were the first to make their appearance have become totally extinct, and have been succeeded by other orders belonging to these classes which made their appearance on the scene at a comparatively late period.

Theories of Evolution.—After having examined the evidences for evolution, we shall now consider some of the theories that have been propounded to explain how evolution could have taken place. Of these it will be here necessary to refer to only three, namely, those which we owe to Lamarck, Darwin, and De Vries.

The Lamarckian Theory.—This was the first important attempt to solve the problem of the means by which evolution has taken place. Lamarck published his views in his *Philosophie Zoologique* in 1809. He held the view that evolution of new forms takes place through changed conditions of life bringing about a change in habits, involving the use of new parts or a different use of old parts, which results finally in the production of new organs and the modification of old ones. He attributed considerable influence to the use and disuse of organs, and held that the development and efficiency

of organs are constantly in proportion to the use of these organs. He further held that all that has been acquired, traced out, and altered during the course of their life (whether as the result of the direct action of environment or indirectly through use and disuse of certain parts to suit new requirements) is preserved by generation, and transmitted to the new individuals which originate from those which have experienced these modifications.

To illustrate these views, we may refer to Lamarck's account of the influence of habits on the remarkable form and stature of the giraffe. This animal lives in the interior of Africa, in places where the earth, almost always arid and without herbage, obliges it to browse on the foliage of trees and to make continual efforts to reach it. As a result of this habit, maintained for a long time in all the individuals of its race, the fore-limbs have become much longer than the hind ones, and the neck has become so much elongated.

There are three distinct factors involved in evolution according to Lamarck, viz., *environmental influences* on the organism, *use and disuse* of organs, and, lastly, the *inheritance of acquired characters*, that is, of changes taking place during the lifetime of an individual. Of these there is a great deal of justification for a belief in the operation in nature of the first two factors—though not necessarily as causal agents for the origin of new species—and great difficulties in the way of the acceptance of the truth of the last assumption (see p. 688). Even if acquired characters were held to be transmissible, the other Lamarckian factors would still be inadequate to account for the development of all the various groups of animals and plants. The theory is consequently not accepted by most biologists at the present time.

Darwinian Theory.—In 1858 Charles Darwin, and simultaneously with him Alfred Russel Wallace, published a very consistent and convincing explanation of evolution known as the theory of Natural Selection. In the year following was published Darwin's epoch-making book, *The Origin of Species*, which succeeded in converting the whole scientific world to a belief in the general doctrine of evolution. In nature every animal and plant form shows an excessive rate of multiplication, and consequently a keen *struggle for existence* ensues. There is also the universal occurrence of variations—that is, no two organisms, however closely related they may be, are precisely alike. Some individuals show favourable variations, others do not. Consequently, it is not merely a question of chance, as to which individuals will survive in the struggle for existence. It is the *fittest that survive*, and the less well adapted perish. Or in other words, *nature*, *i e.*, the conditions under which organisms exist, *selects* and preserves certain variations as they arise, by weeding out their less well adapted competitors, very much as the breeder or the gardener selects variations in domestic animals or cultivated plants. This is called *Natural Selection*. The main points in the theory of Natural Selection are clearly stated in the following chart :—

Proved facts.	Consequences.
A. Rapid increase in number B. Total numbers stationary	Struggle for existence.
C. Struggle for existence D. Variation with heredity	Survival of the fittest.
E. Survival of the fittest F. Change of environment	Structural modifica- ions.

Fig. 209.—Wallace's Chart of the Theory of Natural Selection.

In order fully to comprehend the theory of Natural Selection, let us examine the factors concerned a little more closely.

Prodigality of Production.—The productivity of all living organisms is far beyond the ultimate numbers which can possibly survive, and the reason is this: organisms at their lowest rate of increase reproduce in geometrical ratio, whereas the space they may occupy and the available food supply remain constant. The elephant is the slowest breeder among mammals, but Darwin calculated that a single pair beginning to breed at thirty years and continuing to do so until a century old would produce on the average six young and would have in 750 years, barring accident, nineteen millions of descendants. A rabbit, on the other hand, may have six young in a litter and four litters in a year, and the young may begin to breed at six months, a vastly more rapid rate of increase.

With the invertebrates the prodigality of production may be much greater. Huxley estimated that the descendants of a single green fly, if all survived and multiplied, would at the end of one summer weigh down the population of China. Common house-flies would in the same time—six generations of three weeks each—occupy a space of about a quarter of a million cubic feet, allowing 200,000 to a cubic foot. An oyster may have as many as 60,000,000 eggs. If the progeny of a single oyster survived and multiplied and so on until there were great-great-grandchildren, these would number 66,000,000,000,000,000,000,000,000,000,000,000, and the heap of shells would be eight times the size of the earth.

Woodruff, in his study of *Paramœcium*, has maintained a race for five years, the descendants of one wild individual. In the five years there were 3,029 generations,

the mean rate of reproduction being three divisions in twenty-four hours. All the descendants in each generation could not possibly be preserved and given a chance to multiply, yet were it possible, all the descendants of a single Paramœcium would at the end of five years be found to possess a volume of protoplasm approximately equal to ten thousand times the volume of the earth!

With such extraordinary tendency to over-production on the part of all living matter, it is obviously due to some efficient check upon every species of animal and plant that the numbers are kept within bounds. This check is that which Darwin and Wallace both recognised and called the *struggle for existence*.

Struggle for Existence.—This struggle for existence is the competition constantly going on between all organisms for the possession of conditions in which each may flourish.

For a plant a suitable soil, a certain degree of moisture, and sunlight are necessary. For spots presenting favourable conditions there is constantly going on a competition between individual plants of one species (*intraspecific struggle*) and between the members of different species (*interspecific struggle*). All these plants have also to struggle against the physical environment, against excess of moisture or of drought, against extreme heat or cold, and so forth (*environmental struggle*). The struggle can actually be witnessed when a small plot of ground in a garden is allowed to run to waste. A variety of weeds will soon appear, which will kill the original garden plants. Later on the more hardy weeds will be seen to kill off some of those that first appeared. Plants have not only to compete among themselves,

but also to contend against their numerous animal foes. Of all the young seedlings that sprout up, a fairly large proportion are destroyed by insects, and by snails and slugs. Cattle and goats also produce a marked effect on the vegetation of a country. It is a well-known fact that introduction of goats into certain districts has led to a gradual destruction of the forests in those parts; the seedlings are eaten as they appear, and no young trees are developed to take the place of those that go down with age.

Among animals also there is a keen struggle for existence. Everywhere, more particularly among the lower organisms, indiscriminate destruction of ova and young embryos is going on. Most lower animals produce hundreds, nay thousands of ova every year. By far the greater majority of them are destroyed indiscriminately because they fail to reach a favourable spot for their development or become the food of other animals. Young ones that are not well fitted to cope with the dangers or procure the necessary food are readily destroyed. This intraspecific struggle, that is, struggle against the animal's own kind, is the most severe check of all, for each one's needs are precisely similar, and the competition is in all points. There is also an interspecific struggle, that is, between animals of different kinds. This struggle is more severe between closely related species, because they require much the same conditions as regards food and shelter. Often enough there is a struggle between different animals, so that one may afford food to another.

Man himself is no exception to the rule. Over-population and want of food and space lead to internecine warfare. Man hunts down other creatures to

feed himself, and sometimes falls a victim to the wild animals. He also finds a powerful foe in those tiny microscopic organisms—the germs which are responsible for causing various diseases in him. They feed on the blood or flourish in various other juices of his body, and when the conditions are favourable for their unchecked growth, epidemics are the result. He has also to contend against his physical environment. Drought and consequent scarcity of food, extreme heat or cold, lightning and tempest, cyclones and floods, earthquakes and volcanic eruptions, all act as positive checks to population.

Variation.—Variation is the progressive factor in evolution, for without variation no change could occur and evolution would be impossible. No two organisms are precisely alike. It is a commonly observed phenomenon which everyone can verify for himself. Although the fact that variations do so commonly occur is not open to argument, the causes of variations, their character, and the extent to which parts of an organism may vary are all subjects for debate, and these problems will be briefly discussed in the next chapter.

Heredity.—Heredity means the likeness which an offspring bears to its parents, in its general organisation as well as in the characters of its individual parts. It is the conservative factor in evolution, that which tends to keep the individuals of a species to their normal form ; at the same time, variation having given rise to a new character, heredity causes it to persist. What kinds of variations are transmitted by heredity is one of the most debatable subjects in Biology, and the question will be considered in its proper place. Here it will suffice to

mention that some variations are undoubtedly transmissible by heredity, and it is these which serve as the basis for evolution. Evolution is the change produced in a *race* of organisms ; the mere variation of the *individual*, no matter how profound or how beneficial it may be, is not evolutional until it can be handed on to the offspring, and this is the function of heredity.

Artificial Selection.—Darwin was led to his principle of natural selection by his observations on the struggle for existence and variations. He paid considerable attention to a study of variations as they occur in domestic animals and cultivated plants. Variations are observed to take place in all directions. Man takes good care of those individuals that show particular variations and mates them with other individuals exhibiting variation in a similar direction. Other individuals are not taken good care of and are consequently weeded out. Thus man has been able to select those qualities which seemed most likely to be useful to him or those for which he otherwise took a fancy, and has thus been able to produce, from one and the same original wild stock (Fig. 210), widely different varieties. This process whereby the various breeds or races of domestic animals and plants have been formed is called *artificial selection*. From a single wild species of plants of the order *Cruciferæ*—viz., *Brassica oleracea*—have been produced through cultivation all the varieties of cabbage, cauliflower, broccoli, Brussels sprouts, and other forms, each with a peculiar and strongly marked growth of its own. Many cultivated flowers and fruits show numerous varieties presenting differences in size, colour, texture, flavour, time of ripening, etc.

Among the domestic animals, instances of even more